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EVOLUTION OF PALM OIL MILLS INTO BIOREFINERIES: TECHNICAL, AND ENVIRONMENTAL ASSESSMENT OF SIX BIOREFINERY OPTIONS

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ECI, Biorefinery I: Chemical and Materials from Thermo-Chemical Biomass Conversion and Related Processes, Sep 27 – Oct 2, 2015

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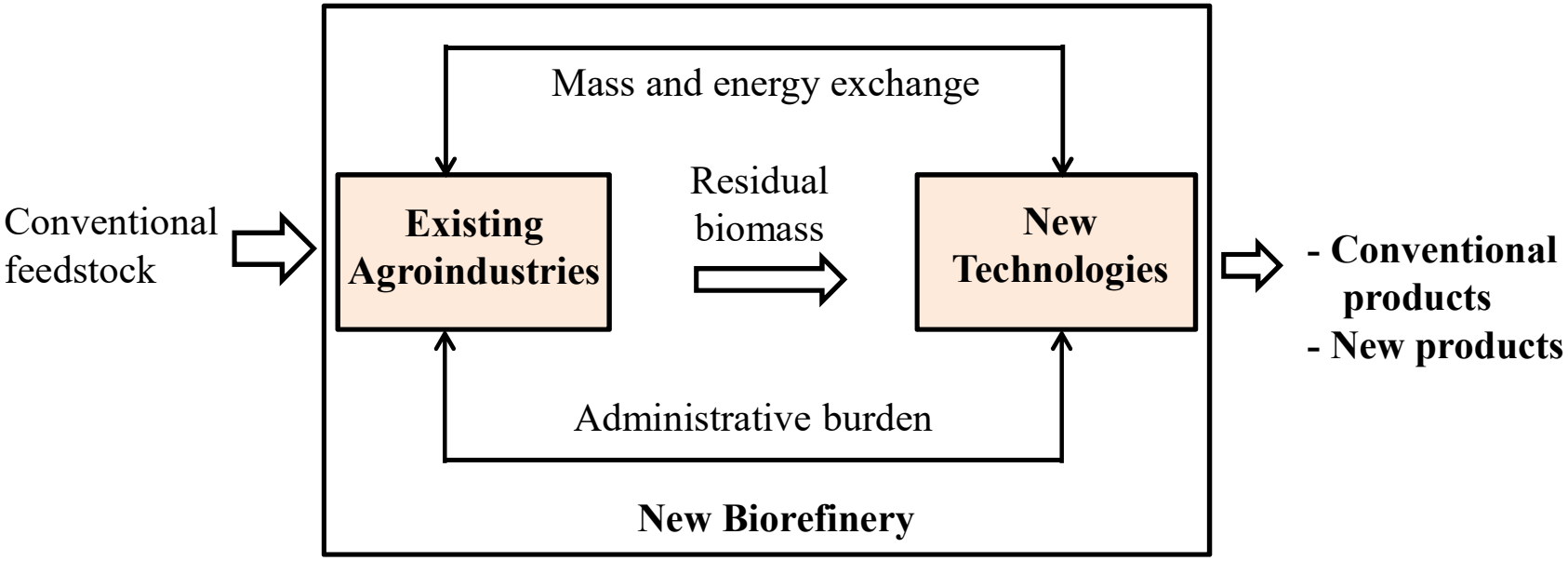
Two approaches to biorefinery implementation

a) Completely new facilities



b) Revamping of existing facilities.

Hurdles on biorefinery selection

- A major scientific issue is how to generate and select the best biorefinery option among those that can be implemented for a given situation.
- The selection requires a deep understanding of the potential technologies, a thorough analysis of the impact of the alternatives on sustainability, societal and economic indicators.
- Different methodologies have been published for selecting biorefinery options.

General Objective

To propose a new methodology for the evaluation of paths to convert of an existing industry into a biorefinery and the implementation of this methodology for the conversion of a Colombian palm oil mill.

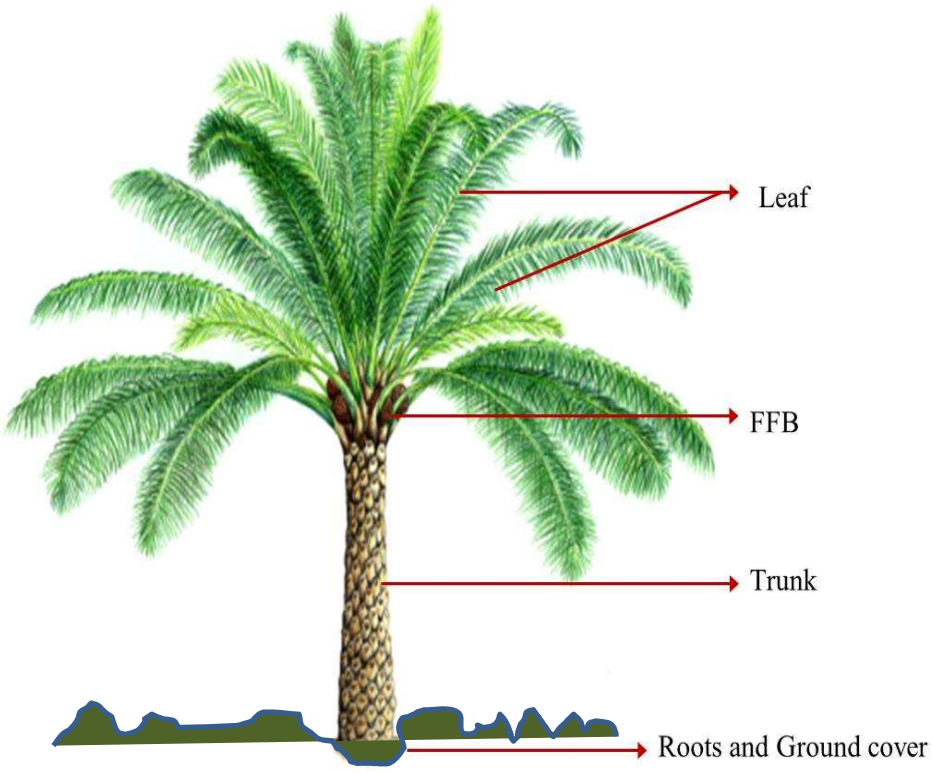
Oil palm sector and palm oil mills (POMs)

- Oil palm agroindustry has been recognized as one of the agricultural businesses where biorefinery concepts can be implemented*.
- Crude palm oil (CPO), the main product of this agribusiness, is the most consumed vegetable oil in the world.**
- The biomass generated by this agro-industry is almost twice the CPO produced, is produced permanently during 25 year, and is located in a single point (POM).

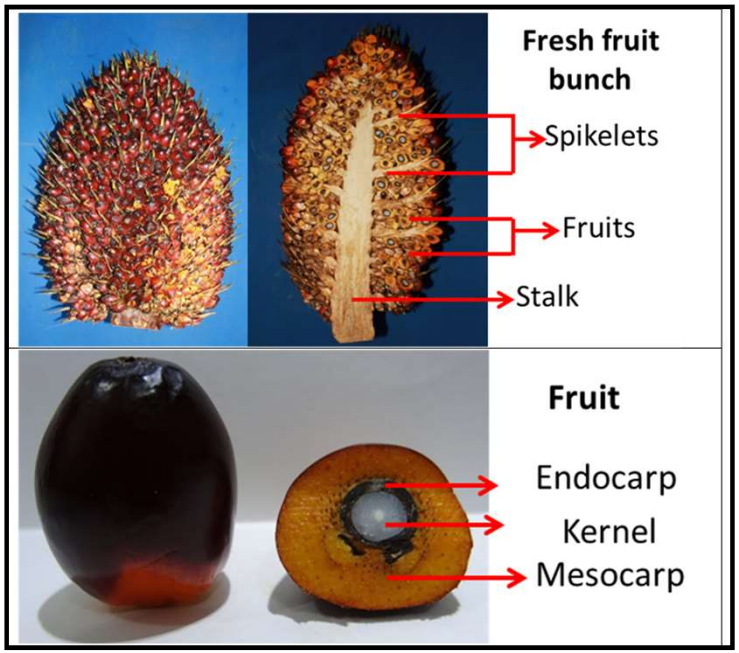
* B. Vijayendran, Bio products from biorefineries - trends, challenges and opportunities, J. Bus. Chem. 7 (2010) 109–115.
**Fedepalma, Statistical Yearbook 2014-The Oil Palm Agroindustry in Colombia and the World 2009 - 2013, Javegraf, Bogotá. D.C.- Colombia, 2014.

Biomass generated at the plantations

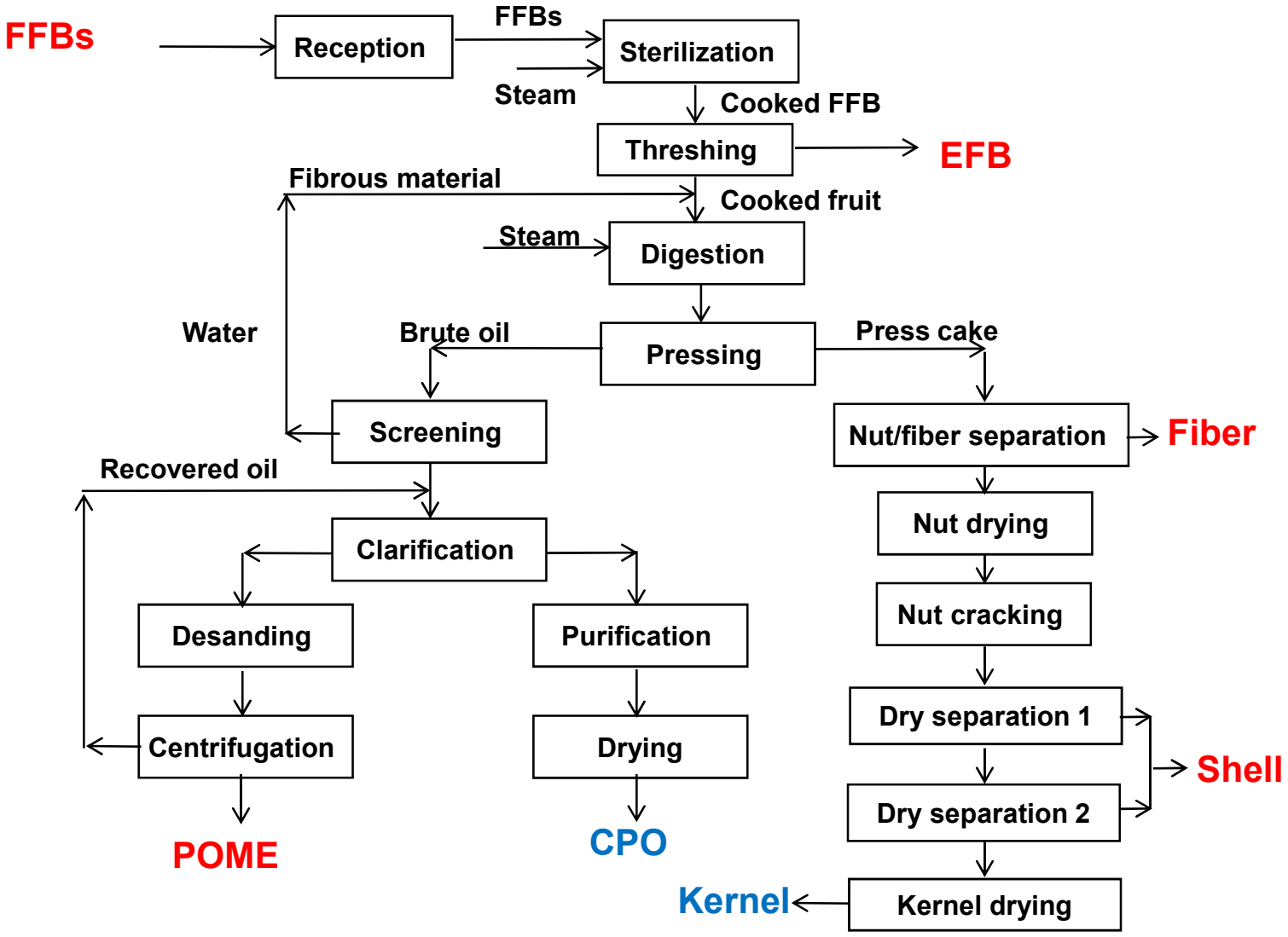
Components of an oil palm



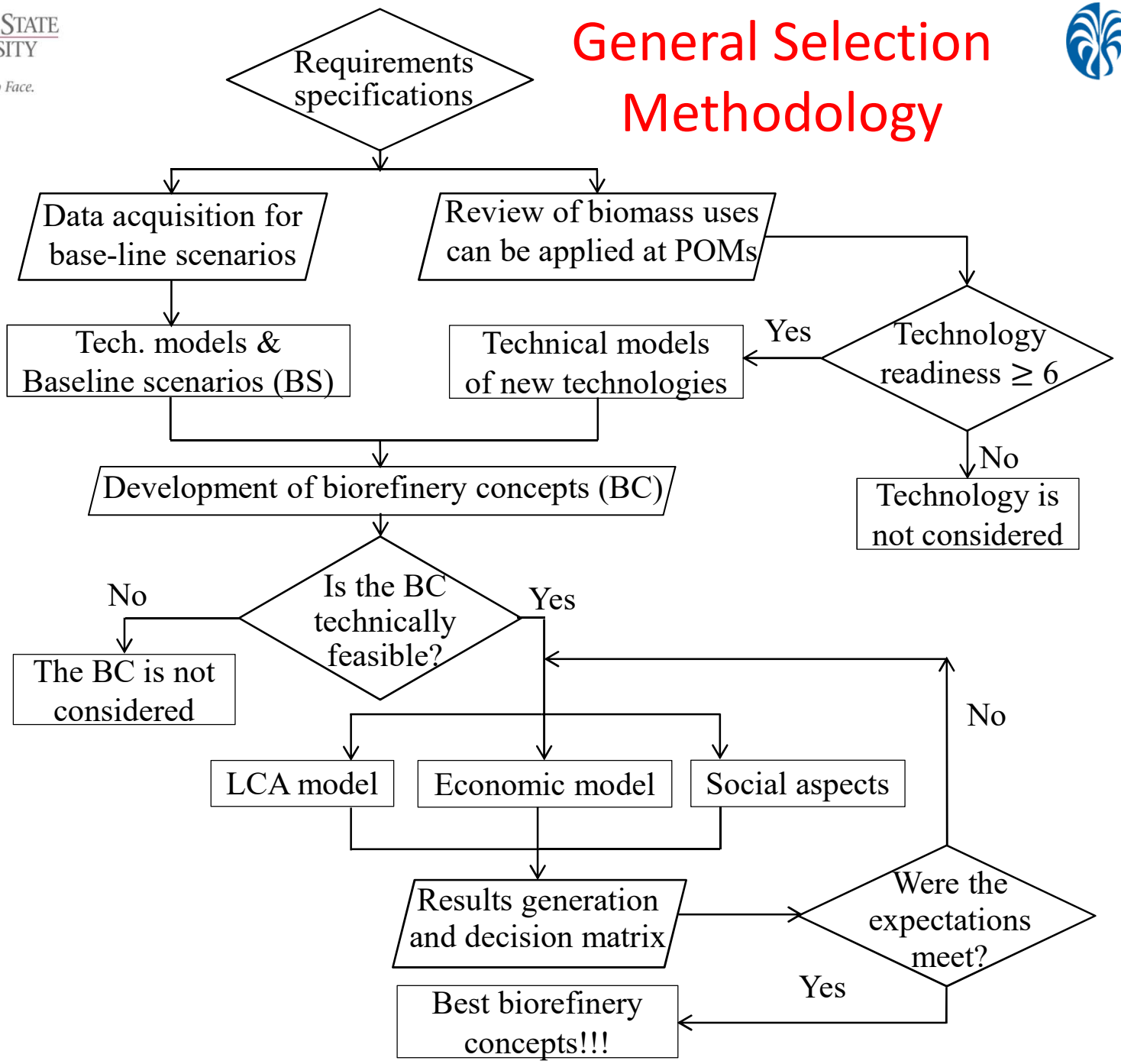
Main components of the fresh fruit bunch (a) and the fruit (b)



Oil palm extraction process



General Selection Methodology



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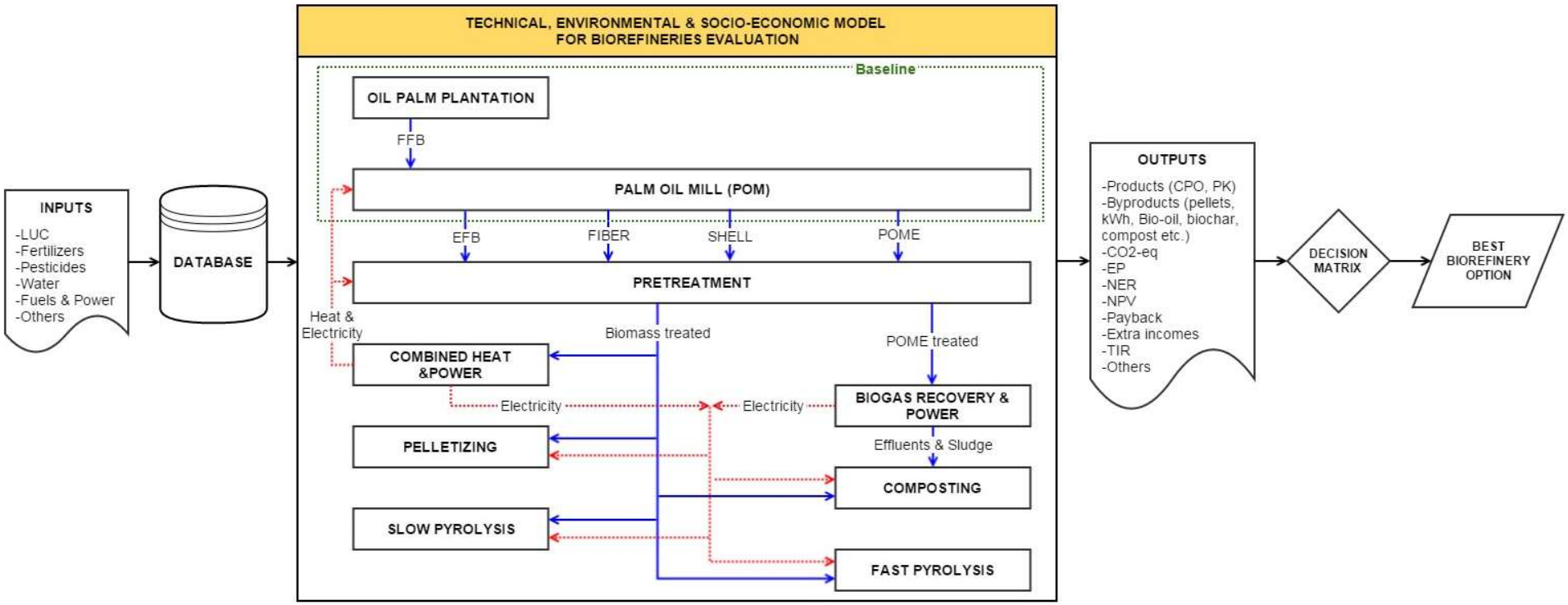
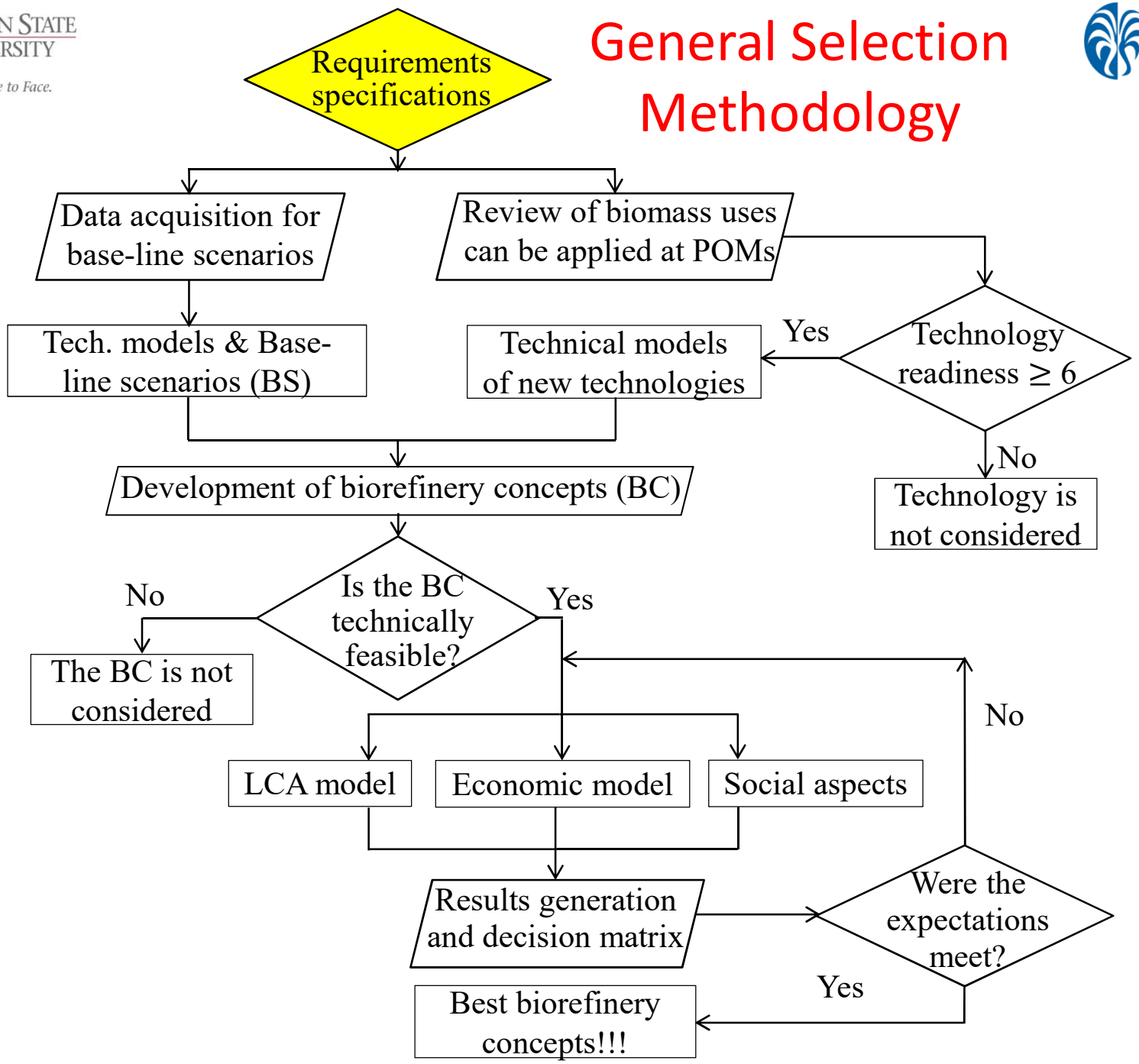
Excel Program



Input variables	Output variables	Functions
2,600	1,450	500

V2: To migrate the Excel version to a web platform.

General Selection Methodology

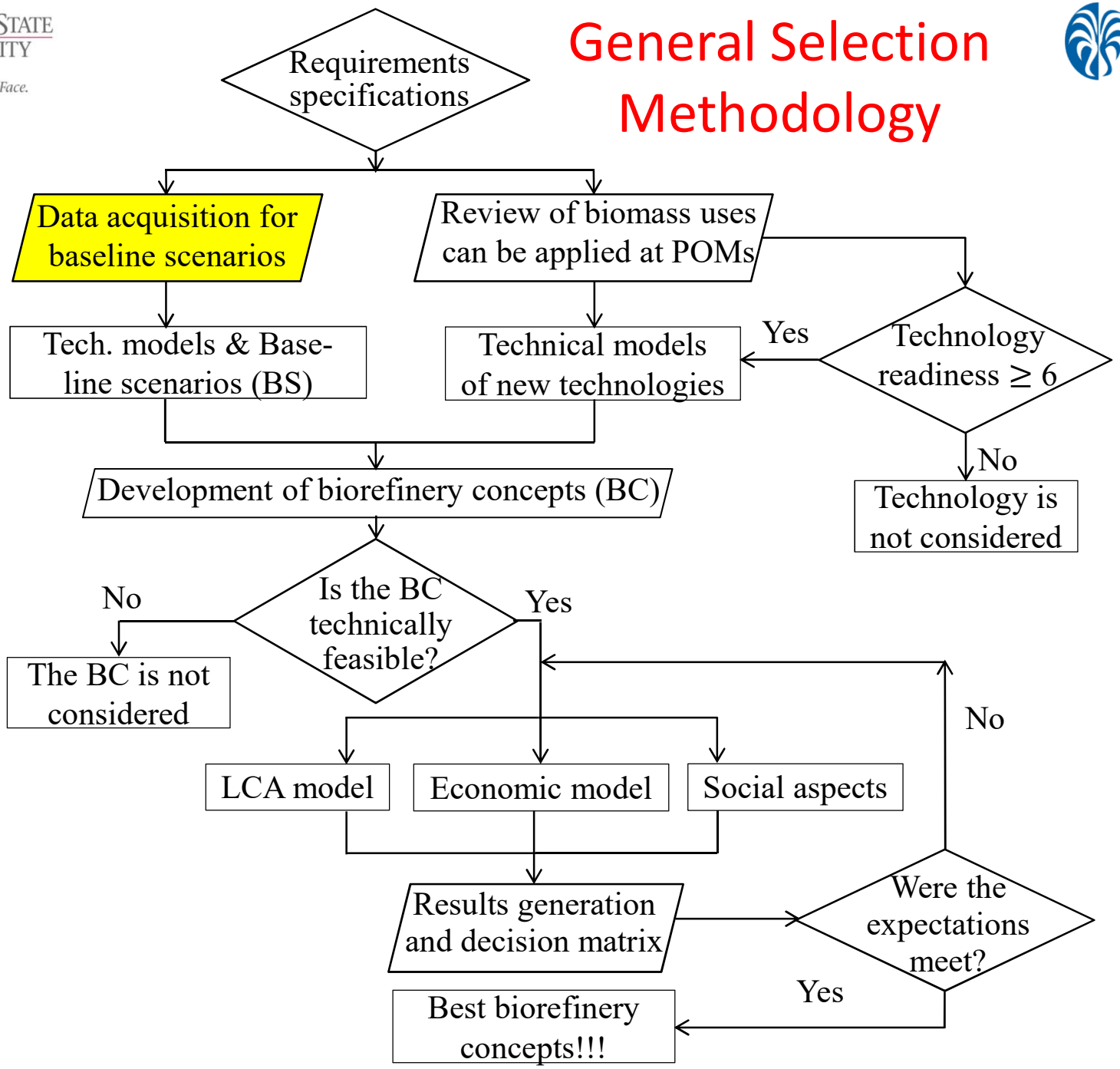


Requirement Specifications

AT THE MILL

- POM Capacity: **30 t FFB h^{-1}.**
- Working time: **5000 hours $year^{-1}$**.
- The POM is not connected to the electrical grid.
- The electricity is generated by low pressure boiler and steam turbine.
- It is required a complementary Diesel fuel to run the POM.
- EFB is disposed in a pit near to the POM

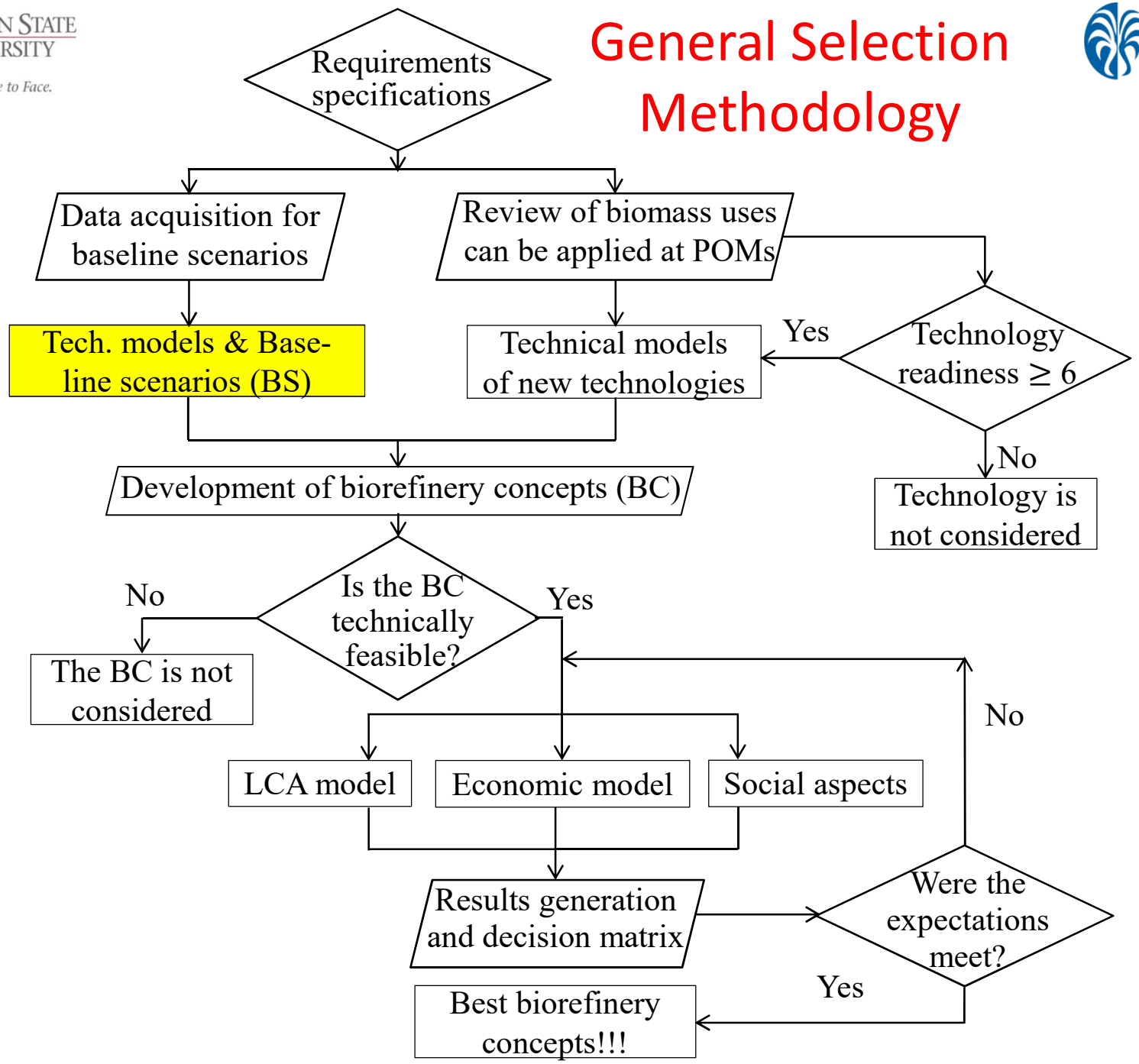
General Selection Methodology



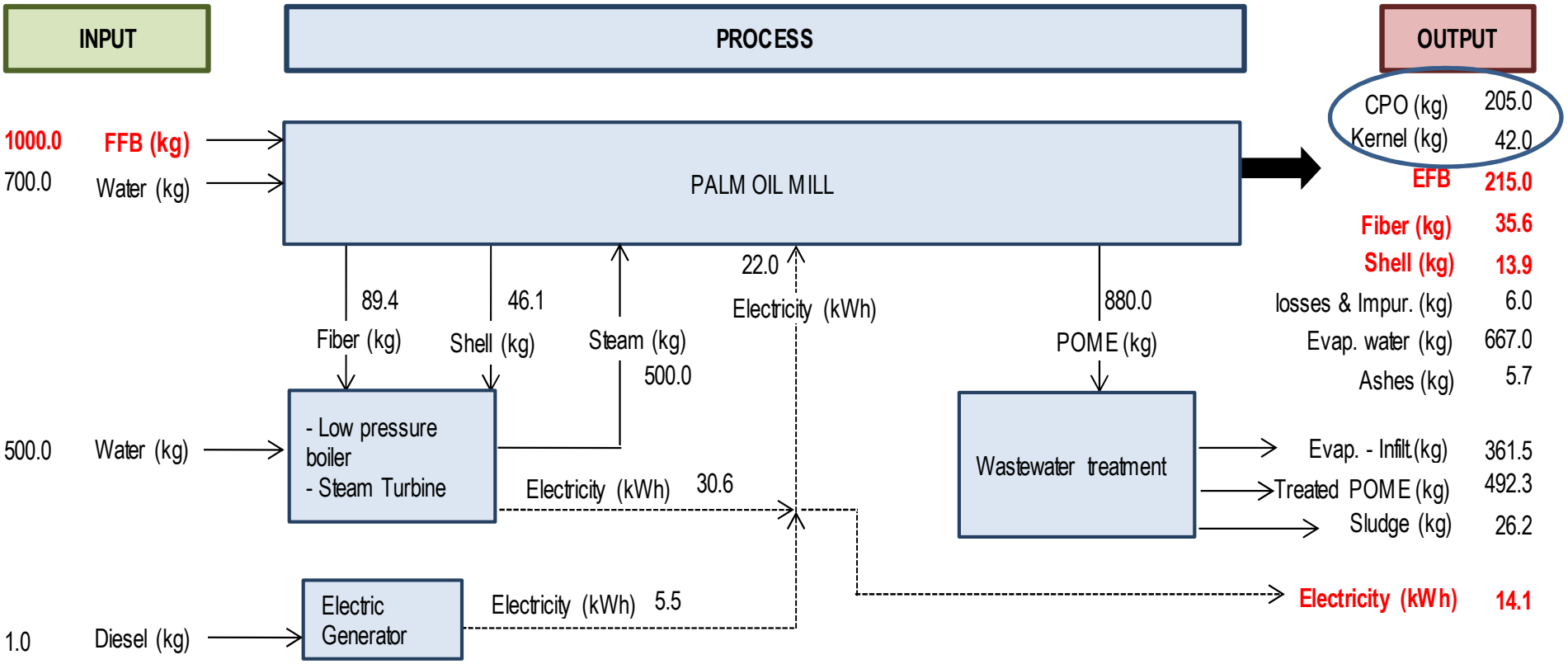
Data acquisition for baseline scenarios

- **At the field**
  - Amount of fertilizers
  - Fuels at the field
  - LUC
- **At the POM**
  - Available biomass
  - Operational conditions
  - Water requirements
  - Biomass characteristics

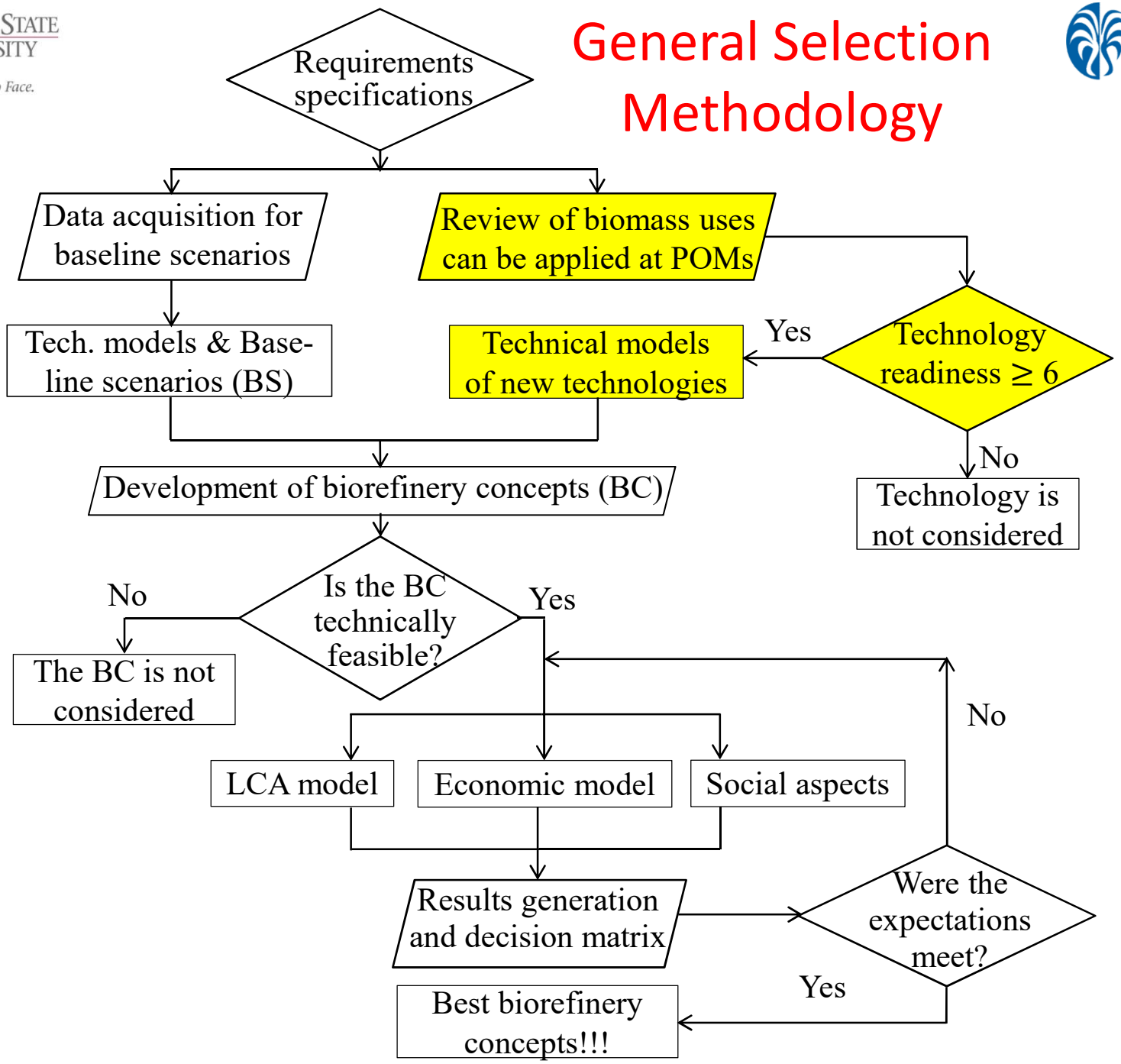
General Selection Methodology



Baseline at the POM



General Selection Methodology



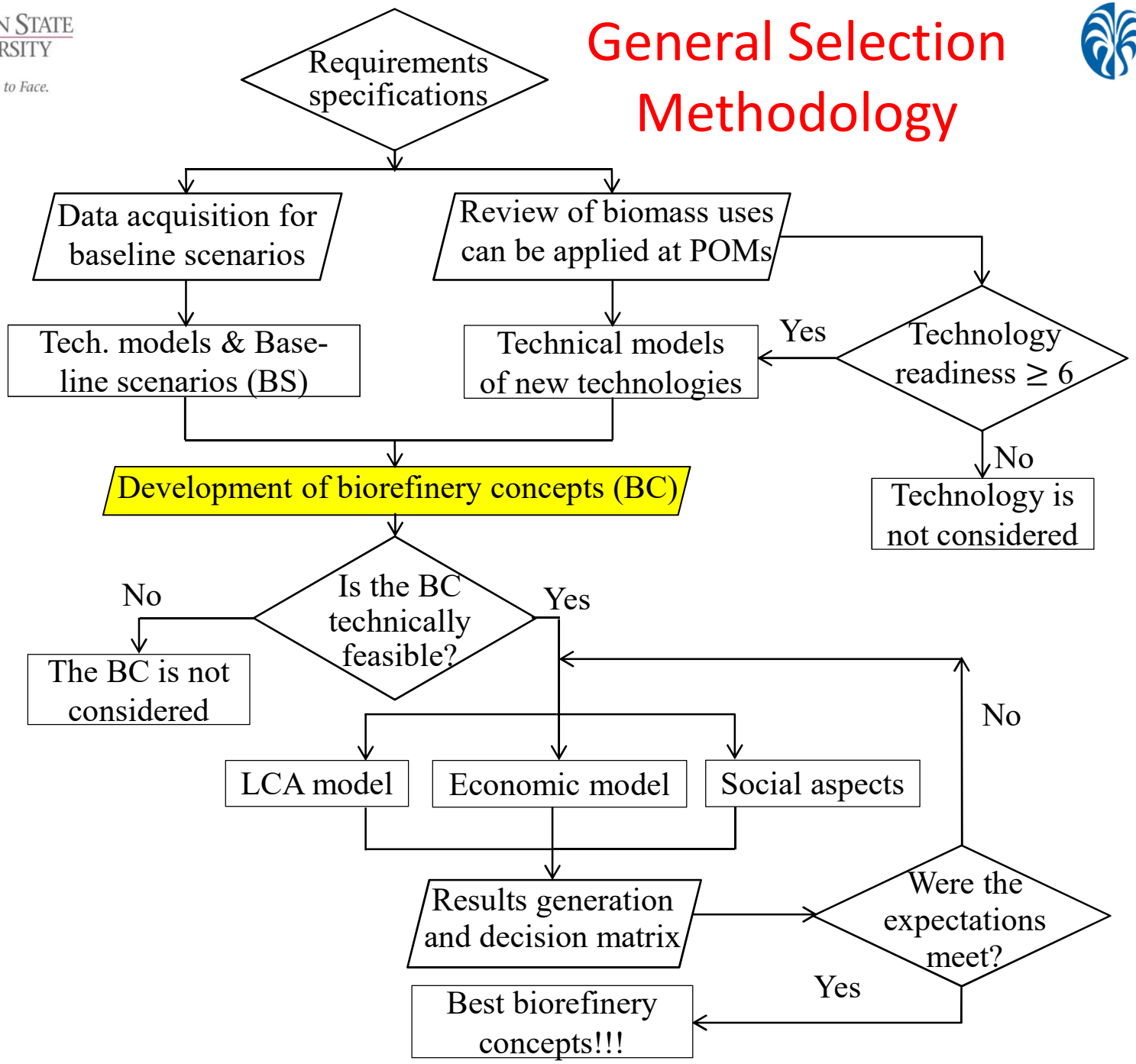
Technology readiness level (TRL) description (Source Overend 2014)

TRL	Description
TRL 1.	Basic principles observed
TRL 2.	CONCEPT: technology concept formulated
TRL 3.	CONCEPT: experimental proof of concept
TRL 4.	VALIDATION: in laboratory
TRL 5.	VALIDATION: in industrial environment
TRL 6.	DEMONSTRATION: in industrial environment
TRL 7.	DEMONSTRATION: prototype in operational context
TRL 8.	SYSTEM: complete and qualified
TRL 9.	SYSTEM: proven and economically competitive

TRL for the new products according with the previous literature review.

Products from "new" technologies	TRL	Products from "new" technologies	TRL
Phenol from POME	TRL 3	Bio-composites	TRL 5
Chemical via catalytic technologies	TRL 3	**Biochar from slow pyrolysis**	**TRL 6**
Enzymes production	TRL 3	**Bio-oil from fast pyrolysis**	**TRL 6**
Cellulosic Ethanol	TRL 4	Activated carbon	TRL 8
Bio-coal from torrefaction	TRL 4	**Pellets and briquettes**	**TRL 8**
Food for ruminants	TRL 4	**Compost**	**TRL 9**
Cellulose pulp and paper	TRL 4	**Biogas production and use**	**TRL 9**
Hydrogen and synthesis gases	TRL 4	**Electricity generation (CHP)**	**TRL 9**
Bio-plastics	TRL 4	**Pretreatment**	**TRL 9**

General Selection Methodology



Proposed Biorefinery Concepts

C1: Biogas) Production of biogas from the anaerobic treatment of the POME and its utilization for electricity generation.

C2: Compost) Composting of empty fruit bunches (EFB), fiber with POME and electricity generation from biogas.

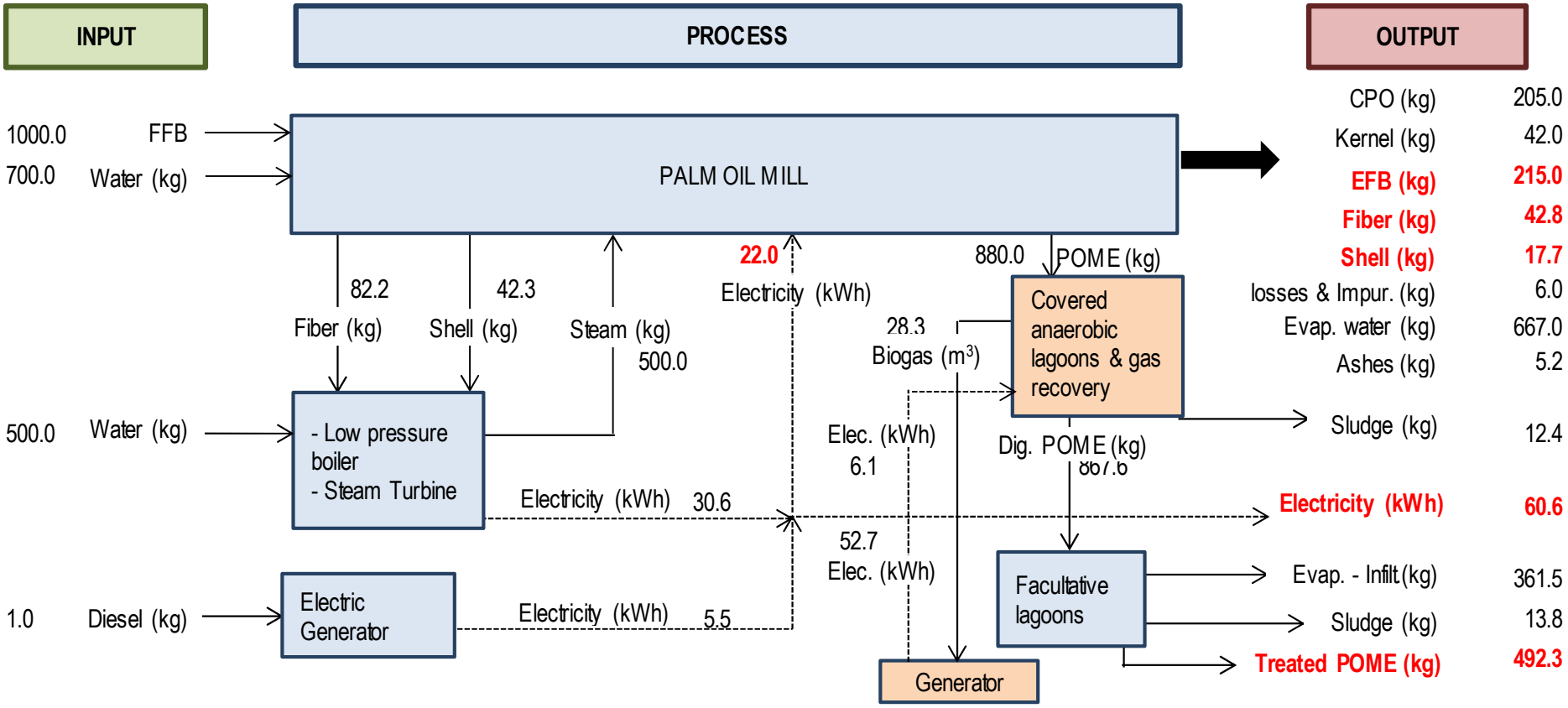
C3: CHP) CHP unit for the utilization of 100% of the biomass to produce electric energy surplus in addition to electricity from the biogas.

C4: Pellets) Pellets production, including biomass drying and biogas uses.

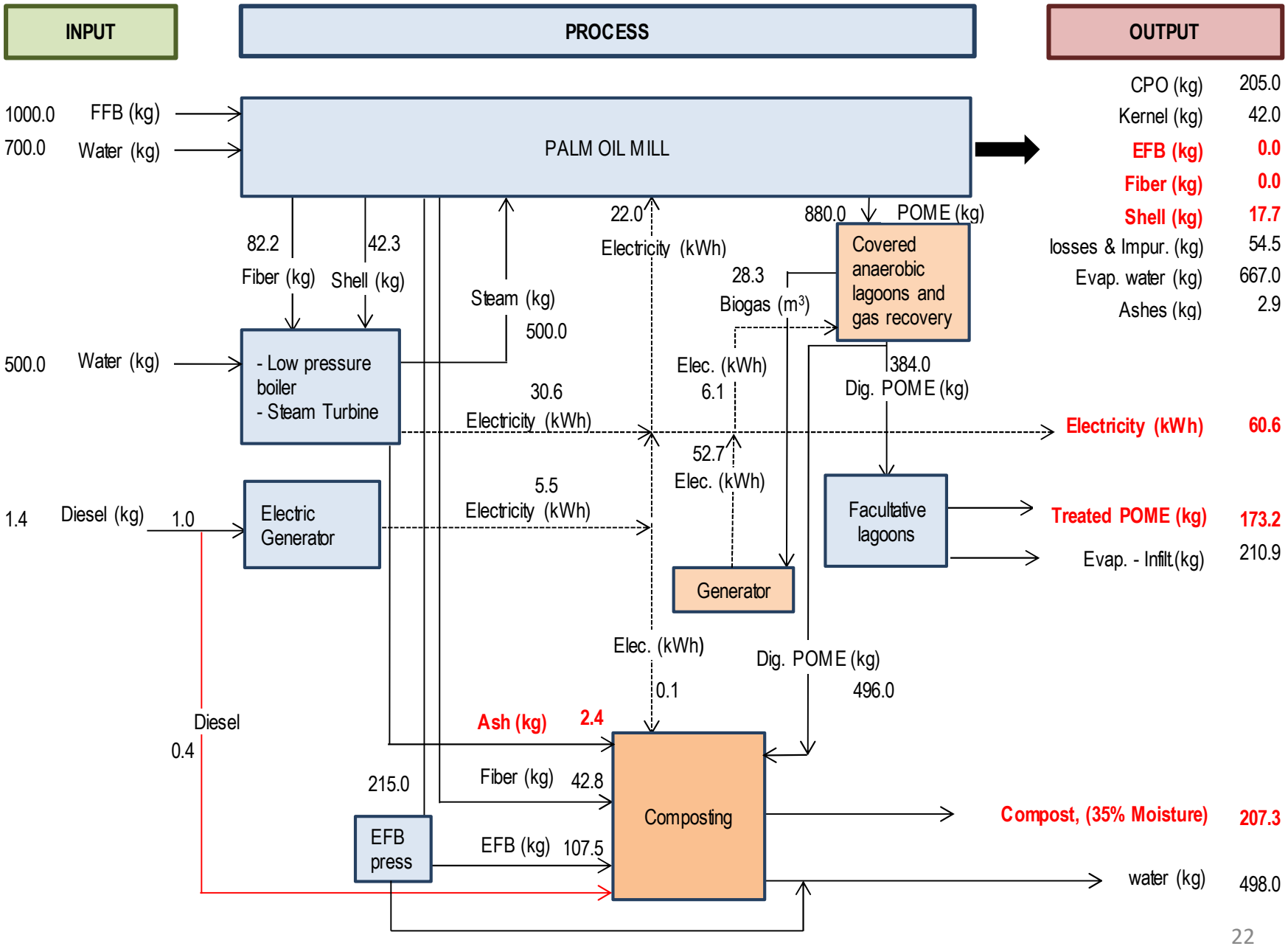
C5: Biochar) Biochar production and biogas use.

C6: Bio-oil) Bio-oil and biochar production plus biogas and syngas burning.

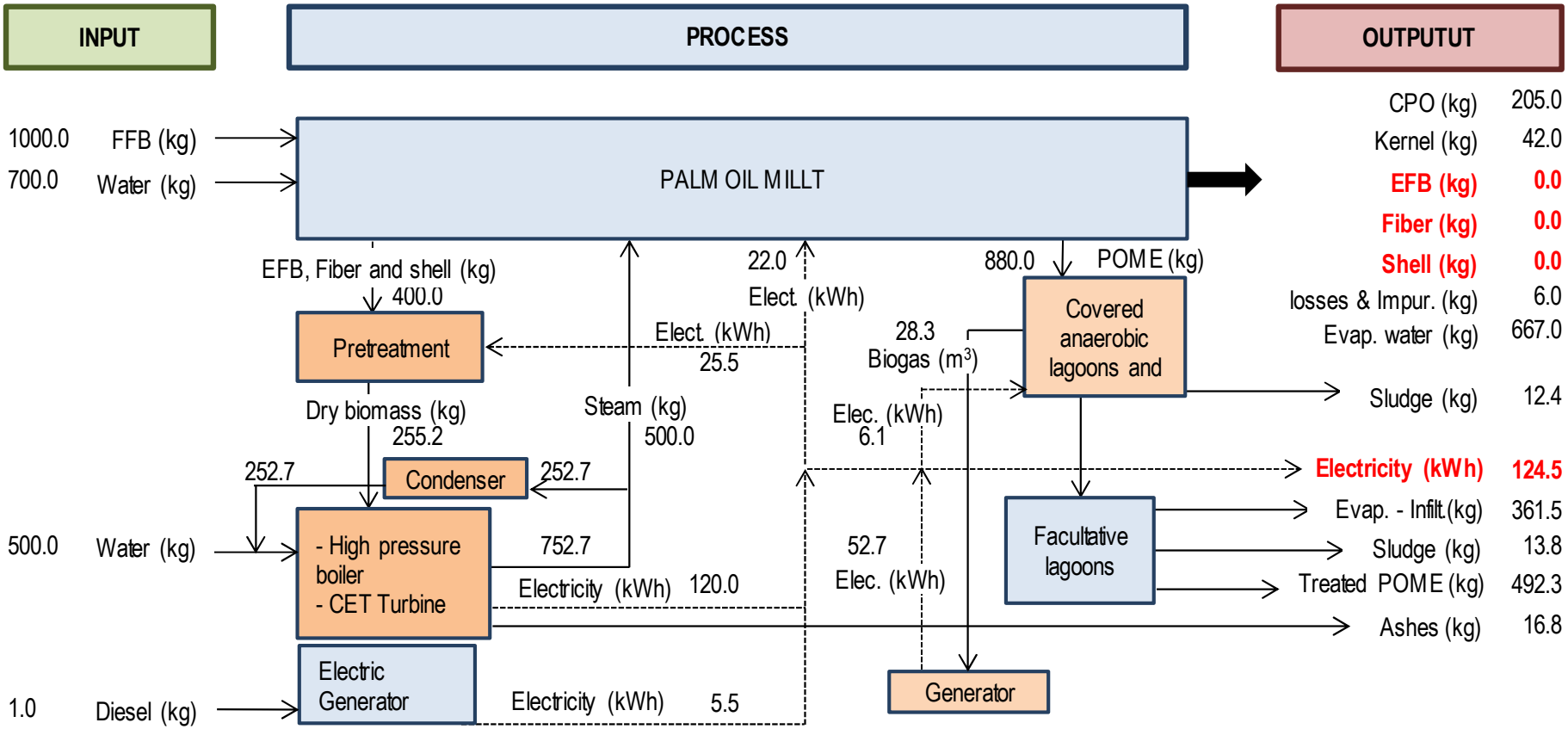
Concept 1. Biogas production



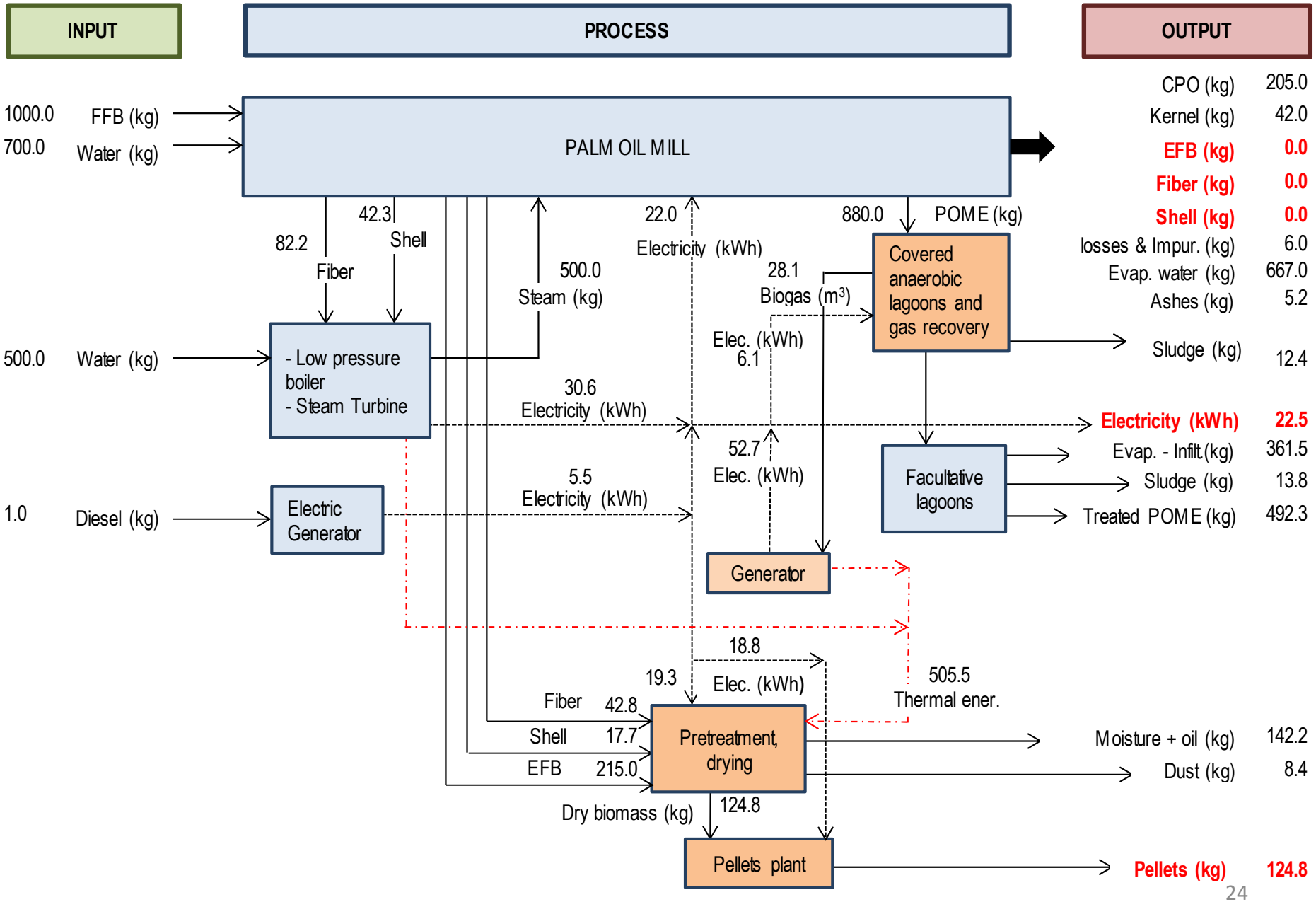
Concept 2. Compost and Biogas



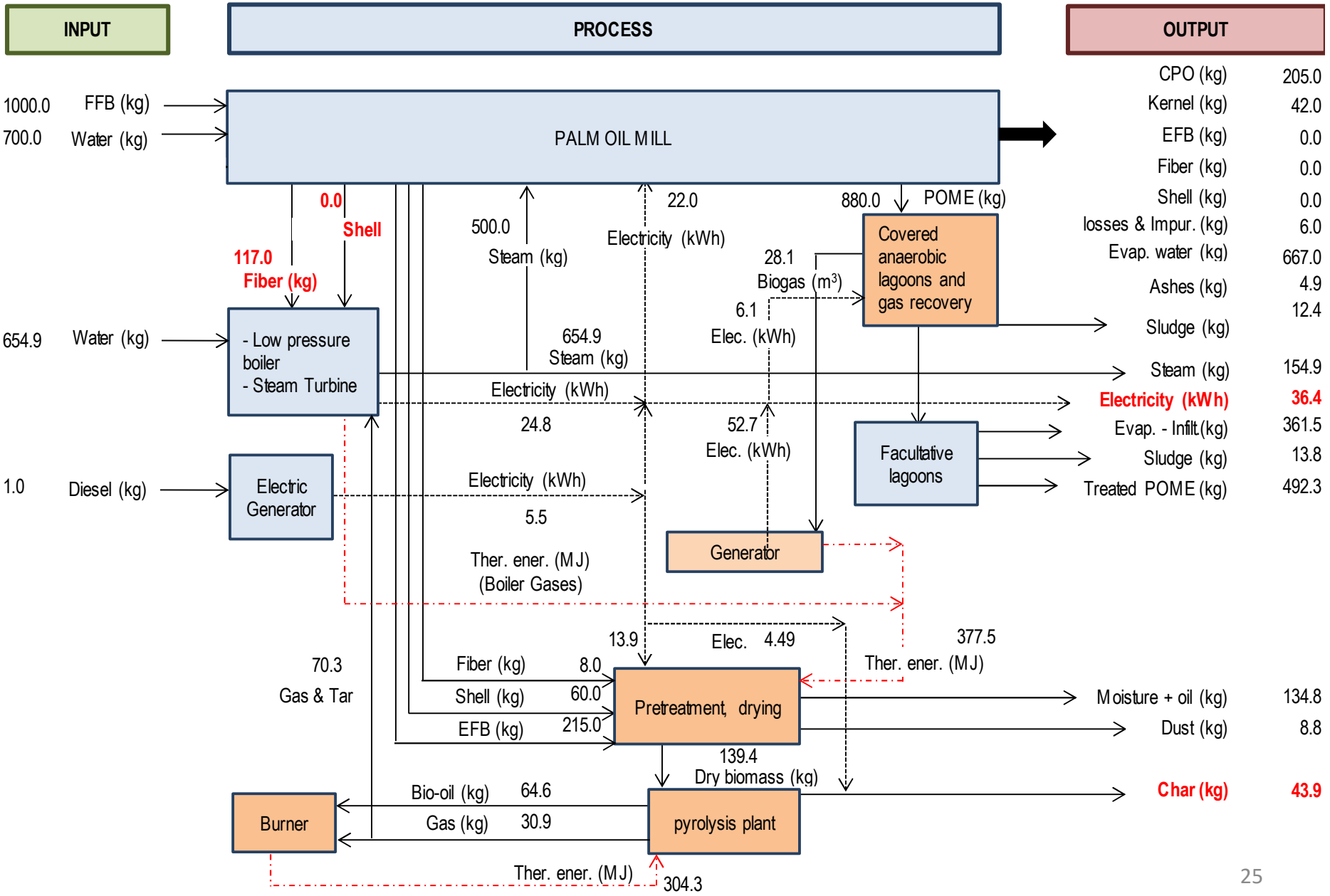
Concept 3. Cogeneration and Biogas



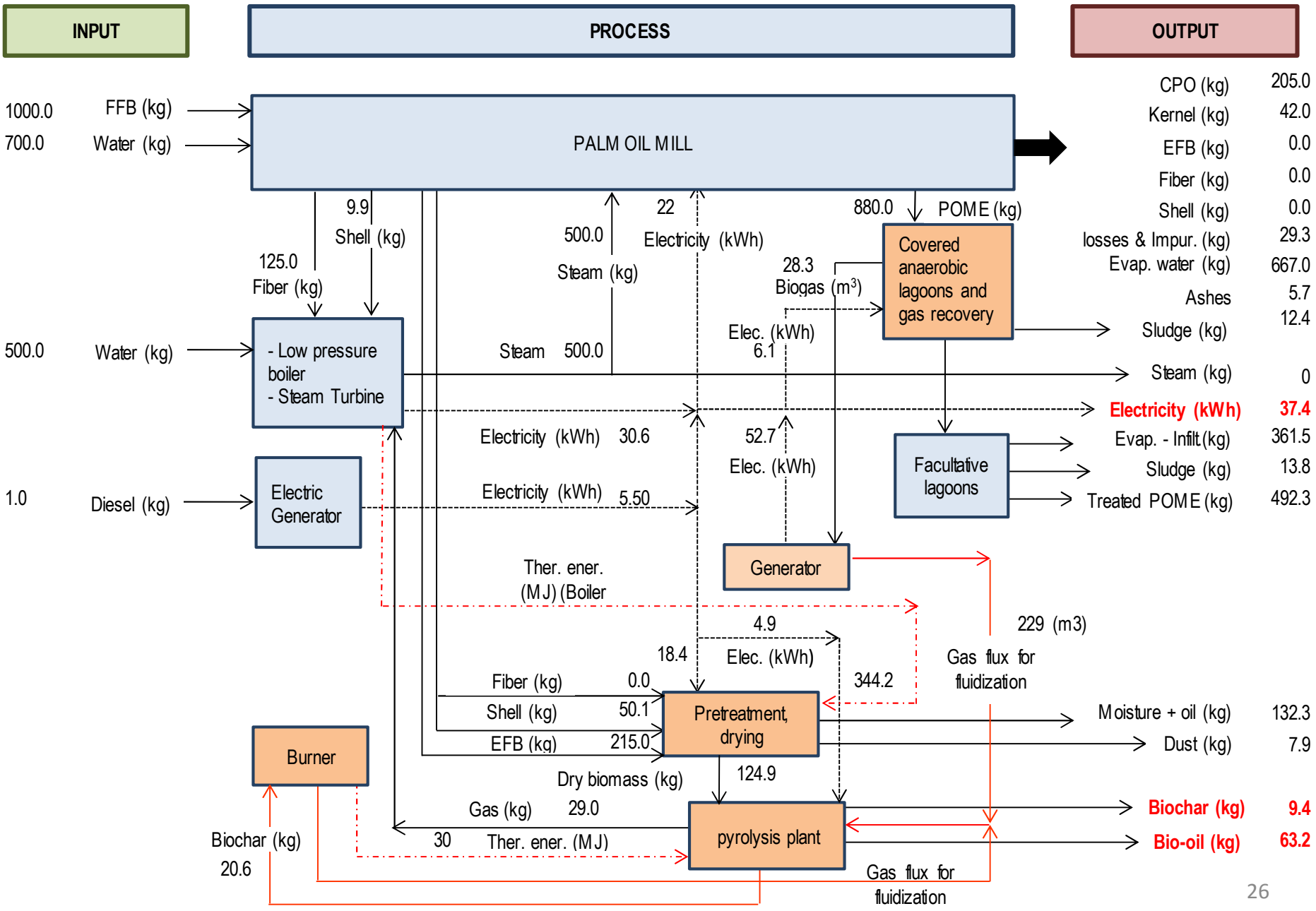
Concept 4. Pellets and Biogas



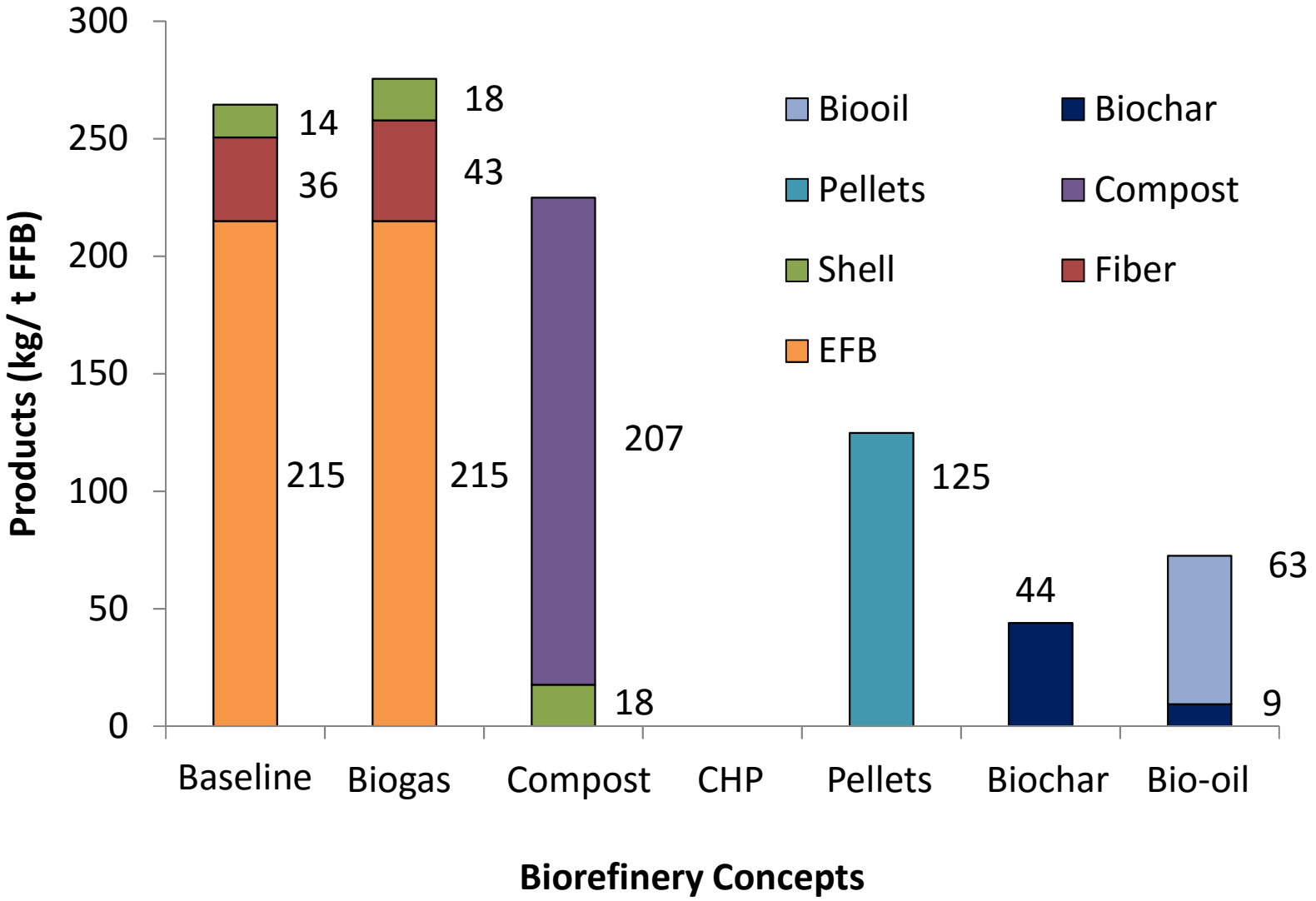
Concept 5. Biochar and Biogas



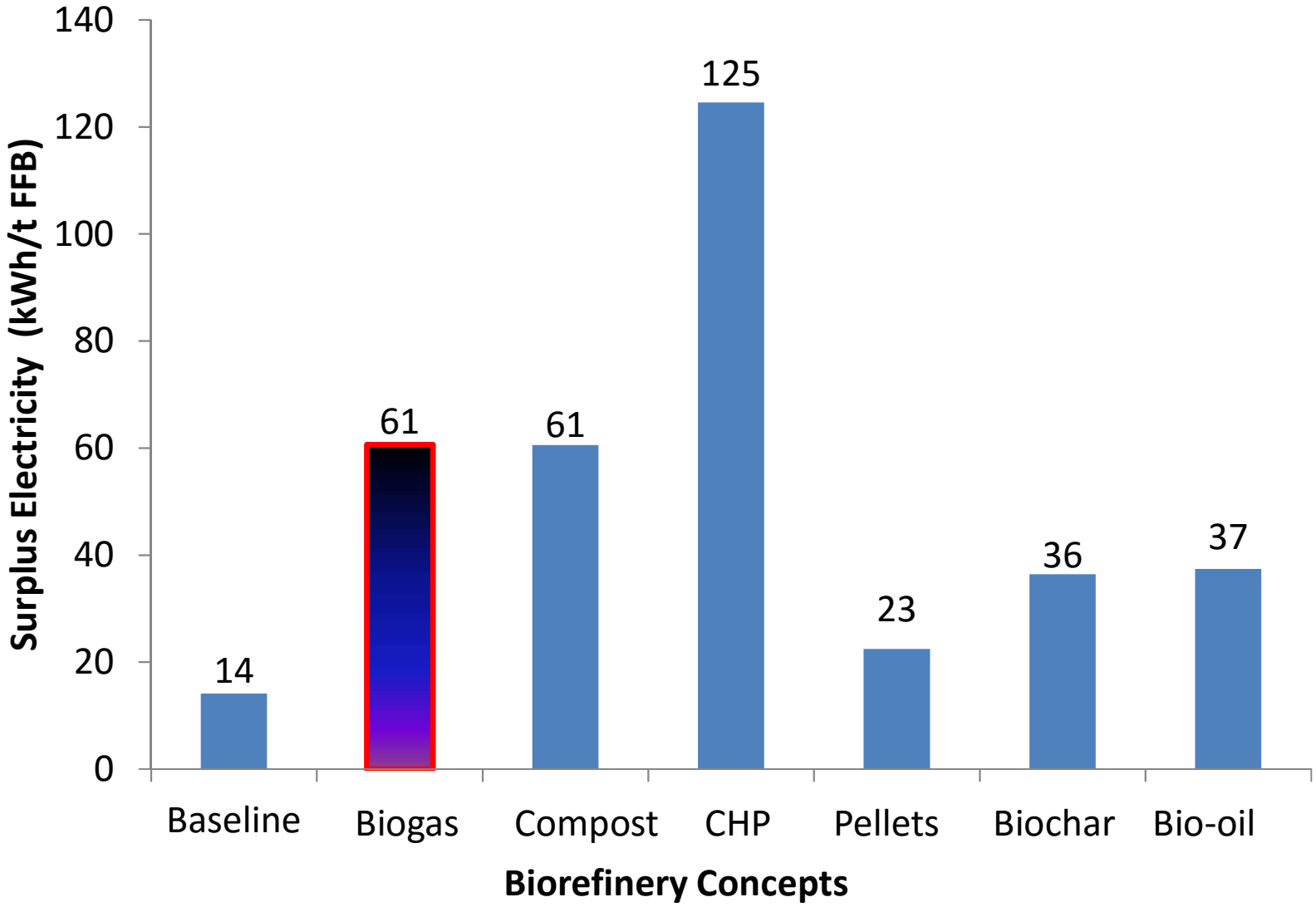
Concept 6. Bio-oil, Biochar, and Biogas



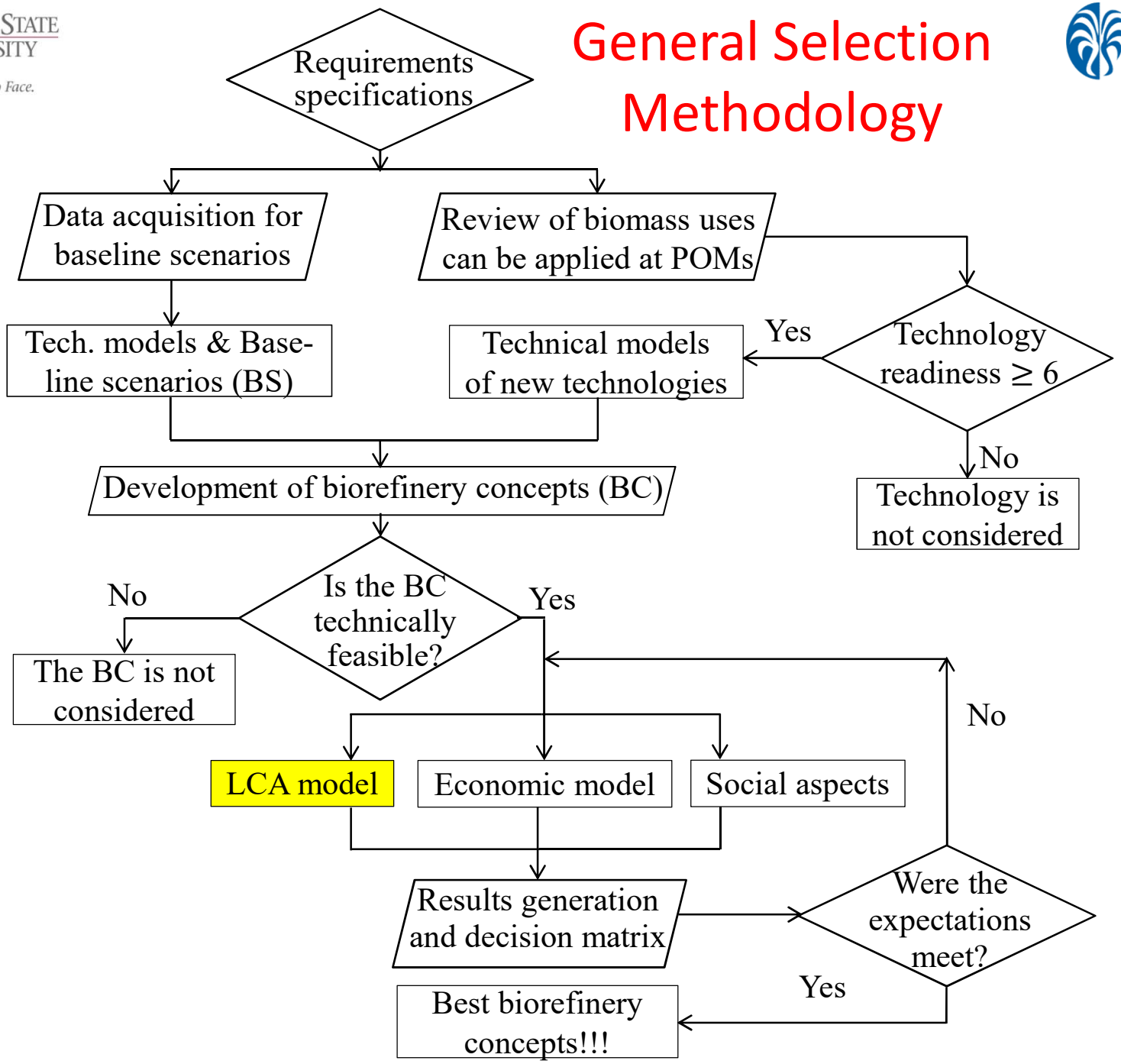
Summary products



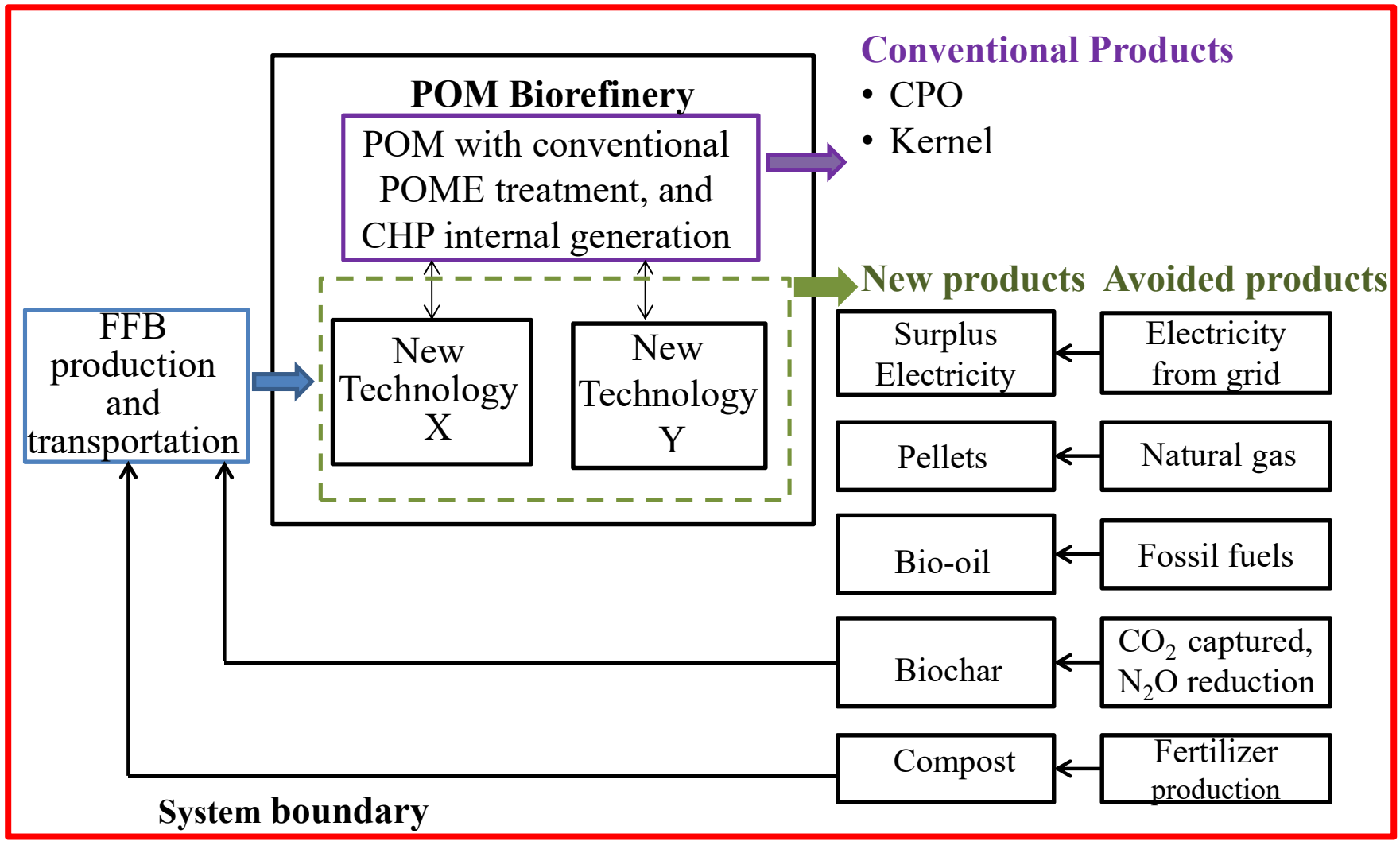
Summary products



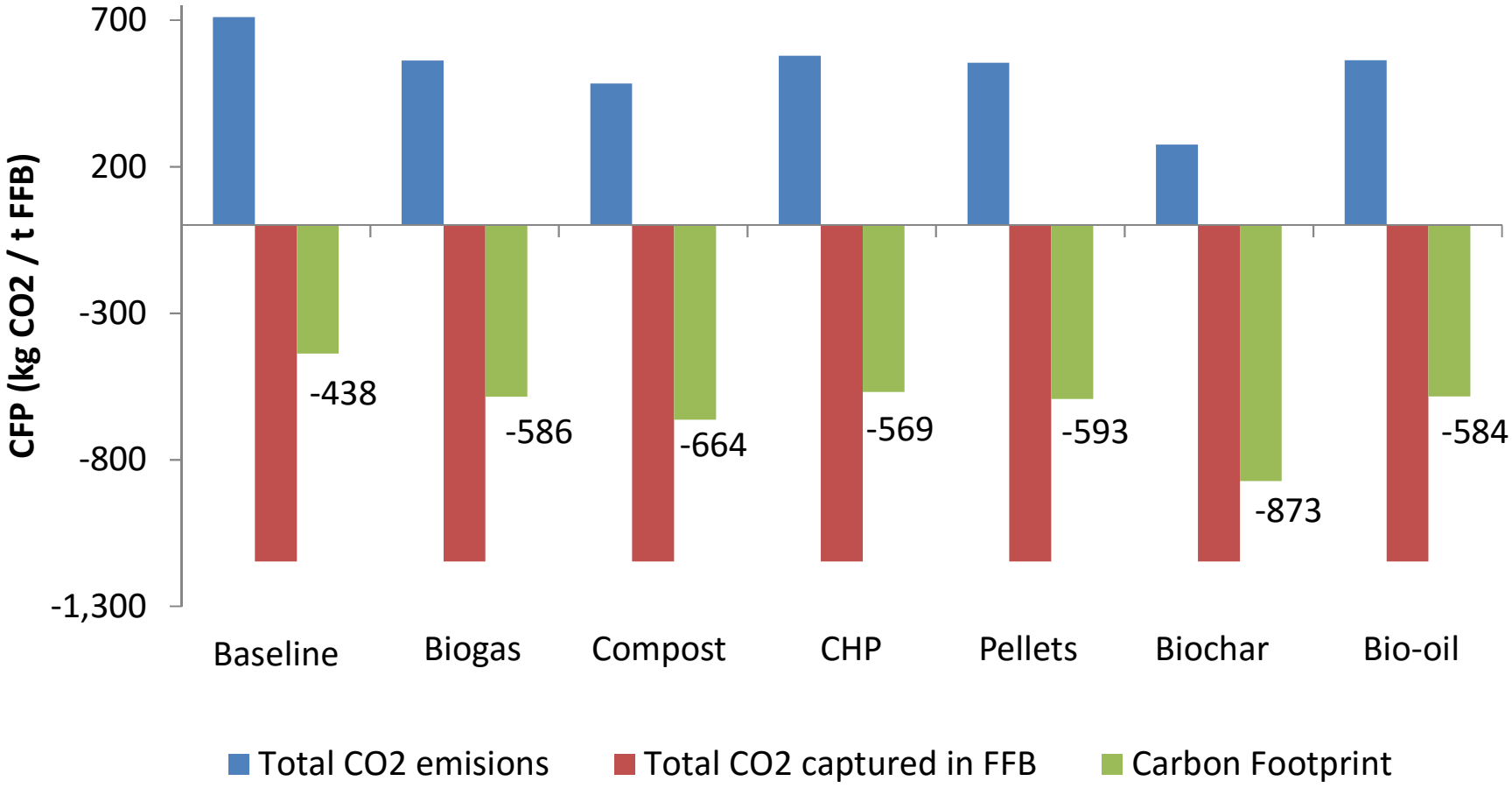
General Selection Methodology



Boundary conditions for LCA of POM biorefinery concepts (Cradle to Gate)



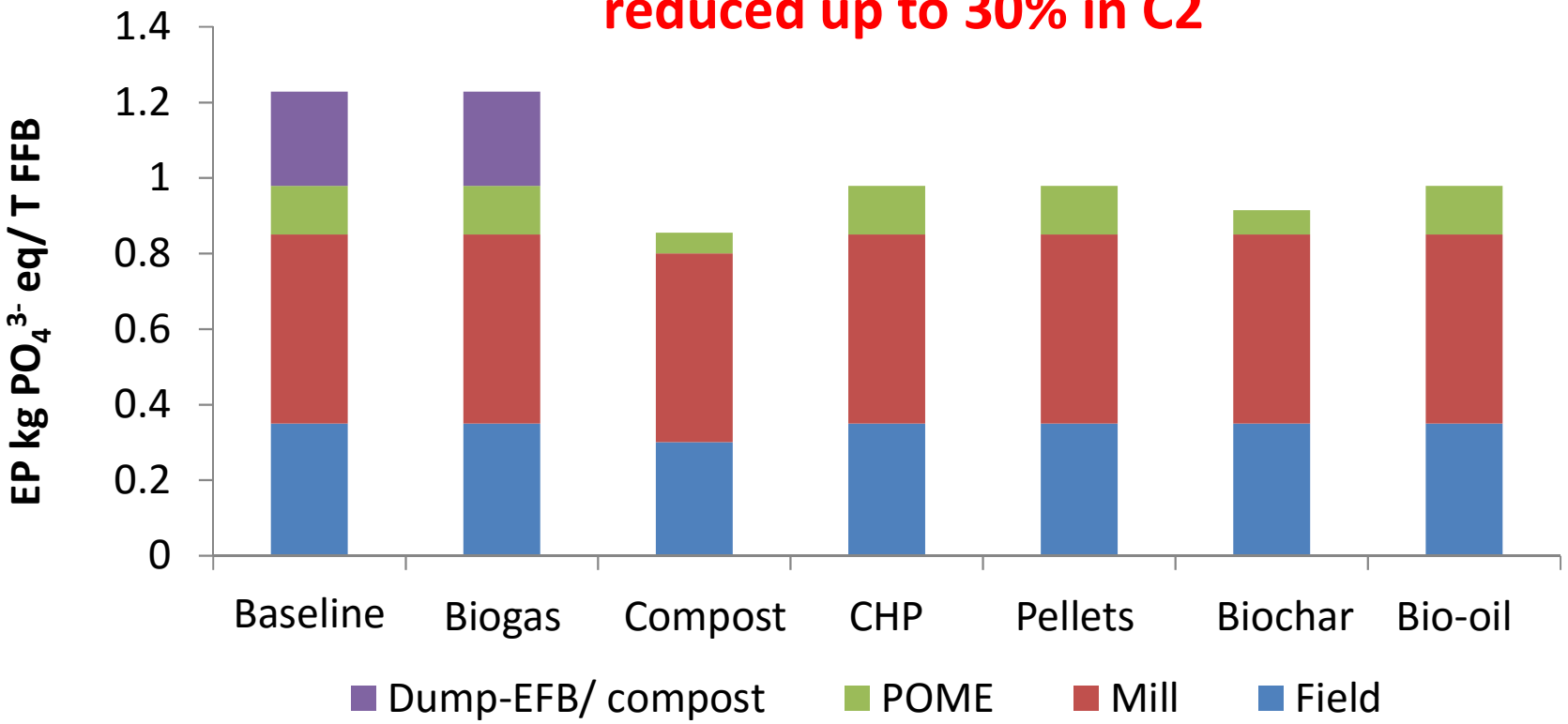
Carbon footprint



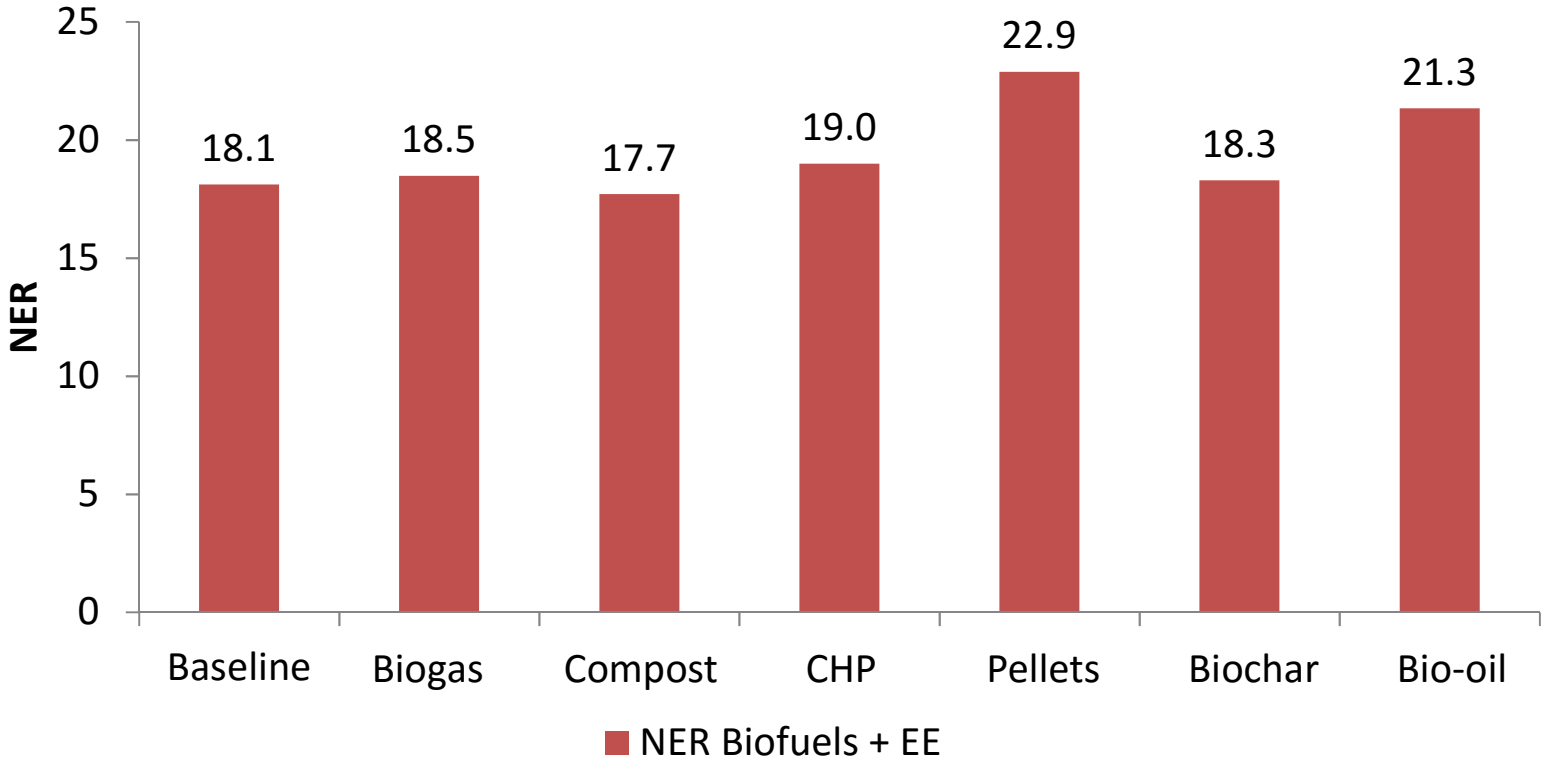
Reduction between 30 and 99% compared with the baseline scenario

LCA Eutrophication Potential

Eutrophication Potential can be reduced up to 30% in C2

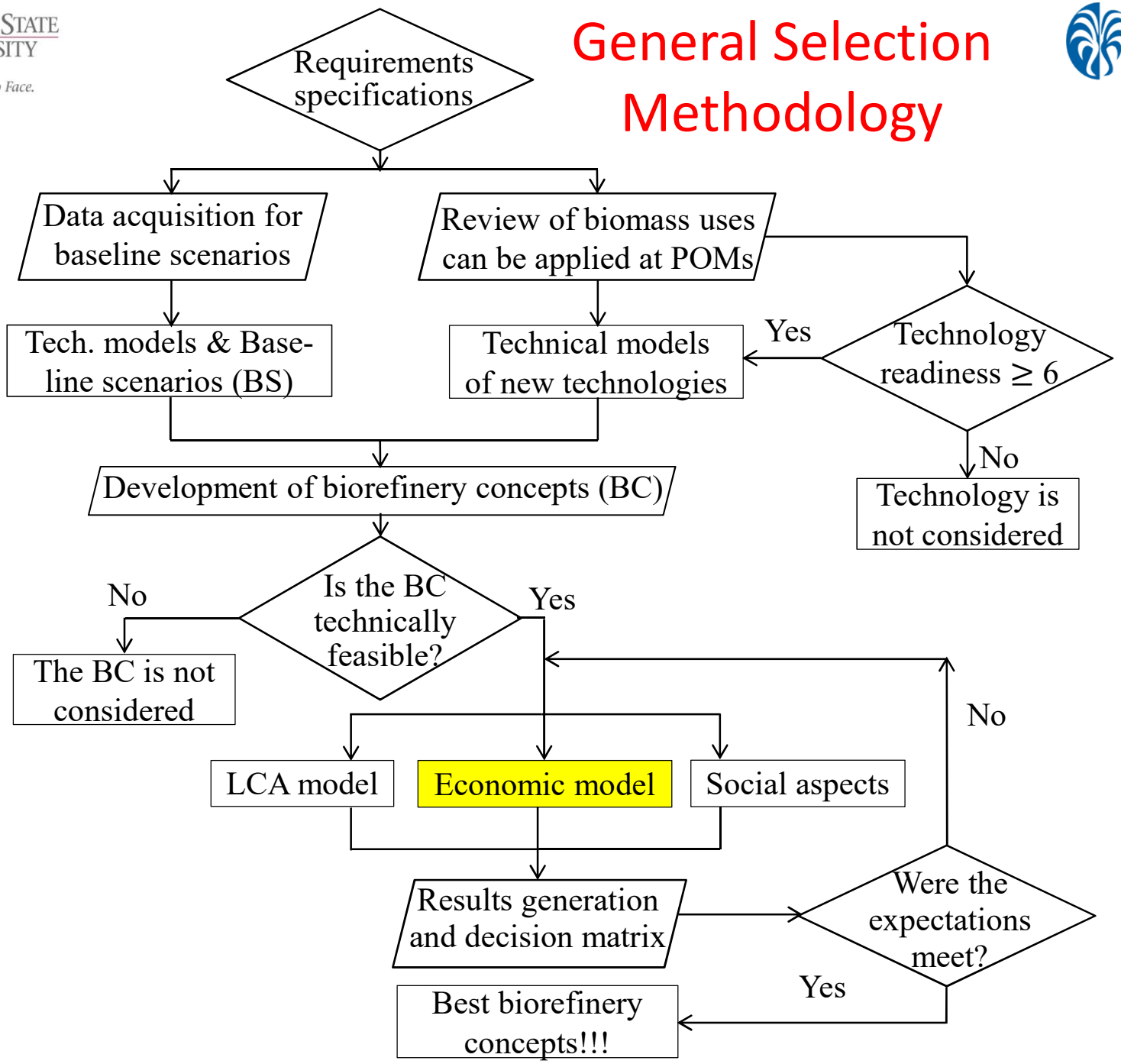


NER



Is improved up to 26% in C4

General Selection Methodology



CAPEX and OPEX for the biorefinery concepts

Production Costs	Biorefinery Concepts					
	Biogas	Compost	CHP	Pellets	Biochar	Bio-oil
CAPEX (USD t^{-1} FFB)	**0.71**	0.87	**2.85**	1.19	2.45	2.38
OPEX (USD t^{-1} FFB)	**1.62**	6.77	6.72	3.39	5.69	**7.33**

Main Economic Indicators among the biorefinery concepts

Economic Indicators	Biorefinery Concepts					
	Biogas	Compost	CHP	Pellets	Biochar	Bio-oil
NPV (Thousands USD)	2,503	3,420	−4,819	13,953	−9,344	6,821
IRR (%)	24	27	3	56	---	20
Payback period (years)	6	5	---	3	---	8
Extra incomes USD t^{-1} FFB	3.3	4.5	1.9	12.8	−2.1	9.6

Minimum sale prices to achieve economic feasibility of the biorefinery concepts

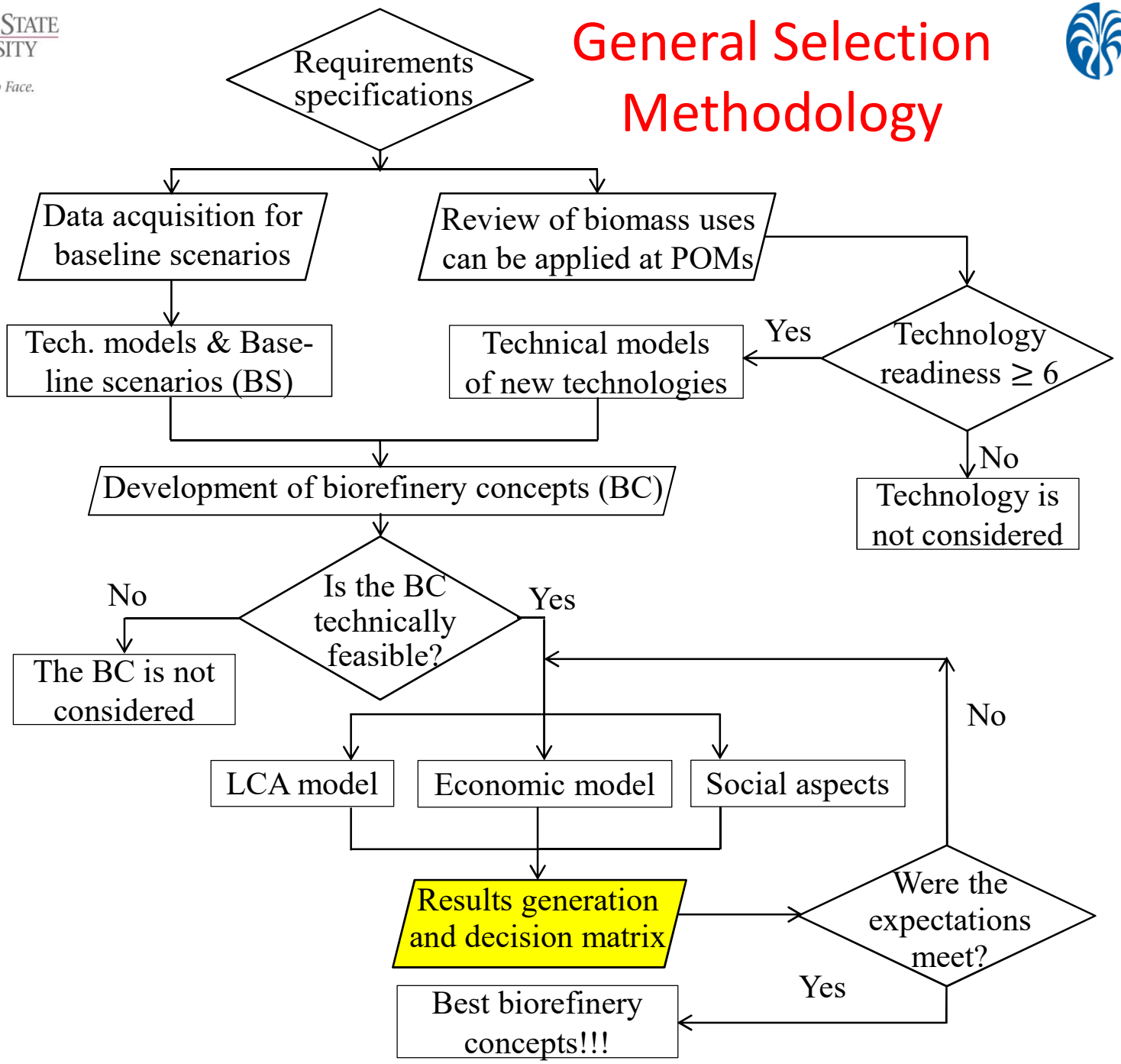
Biorefinery Concepts	Products from the biorefinery concepts				
	Electricity (USD kWh^{-1})	Compost (USD t^{-1})	Pellets (USD t^{-1})	Biochar (USD t^{-1})	Bio-oil (USD t^{-1})
C1	0.062				
C2	0.092	19.46			
C3	**0.121**				
C4	0.092		40.75		
C5	0.092			**216.30**	
C6	0.092			60.00	162.72

Social Aspects

Total labor per shift per each biorefinery concepts

	Biogas	Compost	CHP	Pellets	Biochar	Bio-oil
Technicians	0.5	1	0.5	1	1	1
Operators	1	5	4	6	6	7
Total	**1.5**	**6**	**4.5**	**7**	**7**	**8**

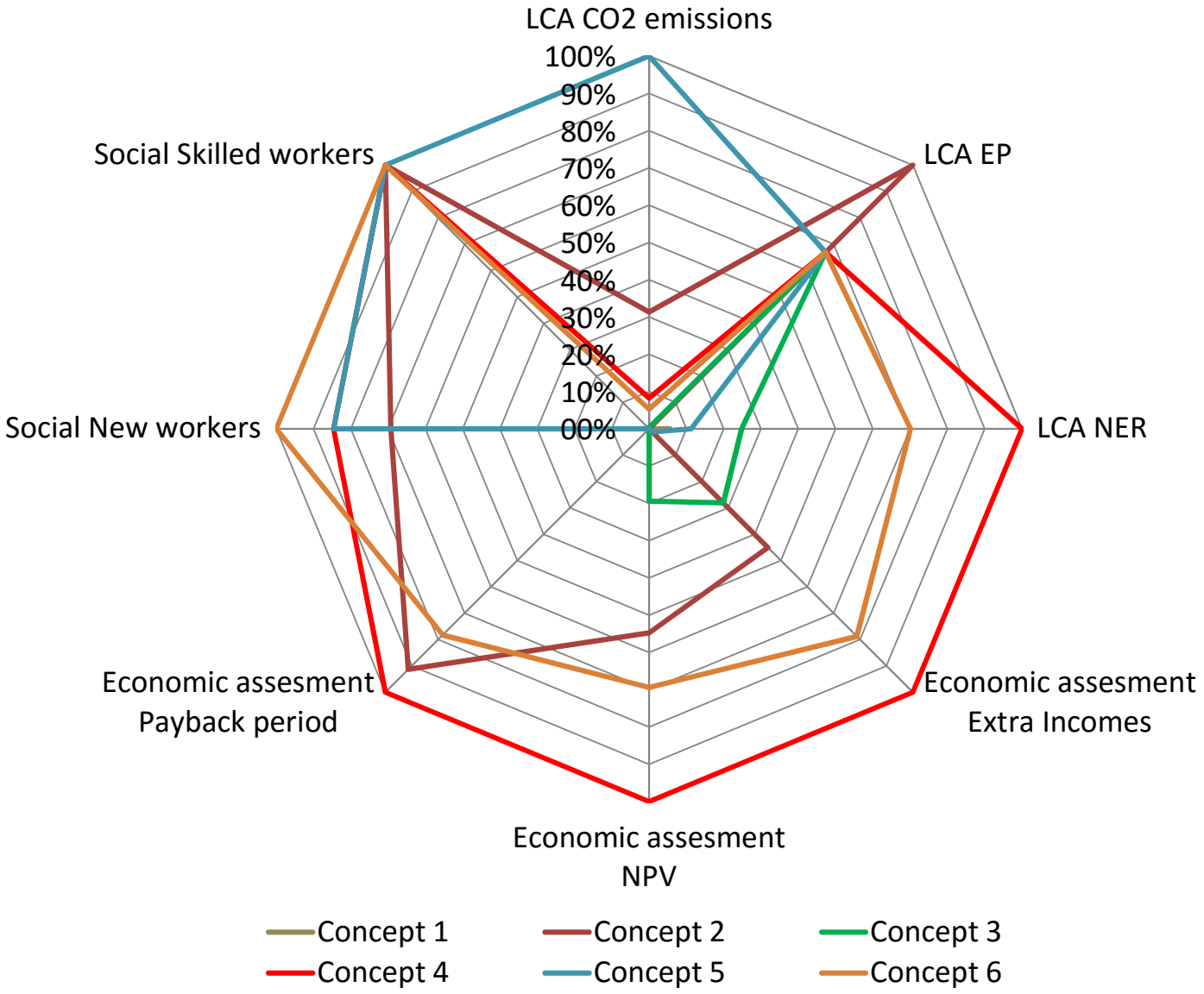
General Selection Methodology



Results Generation (Summarized Results)

Cs	LCA			Economic Assessment			Social	
	CO_2 eq. (kg CO_2 t^{-1} FFB)	EP (kg PO_4^{3-} eq t^{-1} FFB)	NER (MJ MJ^{-1})	Extra Inc. (USD t^{-1} FFB)	NPV (USD) (x1000)	P-back period (years)	New Jobs (#)	Skills (#)
Biogas	−585.6	1.23	18.5	3.3	2,503	6	1.5	0.5
Compost	−663.7	0.86	17.7	4.5	3,420	5	6.0	1.0
CHP	−569.4	0.98	19	1.9	−4,819	---	4.5	0.5
Pellets	−593.3	0.98	22.9	12.8	13,953	3	7.0	1.0
Biochar	−872.6	0.98	18.3	−2.1	−9,344	---	7.0	1.0
Bio-oil	−584.4	0.98	21.3	9.6	6,821	8	8.0	1.0

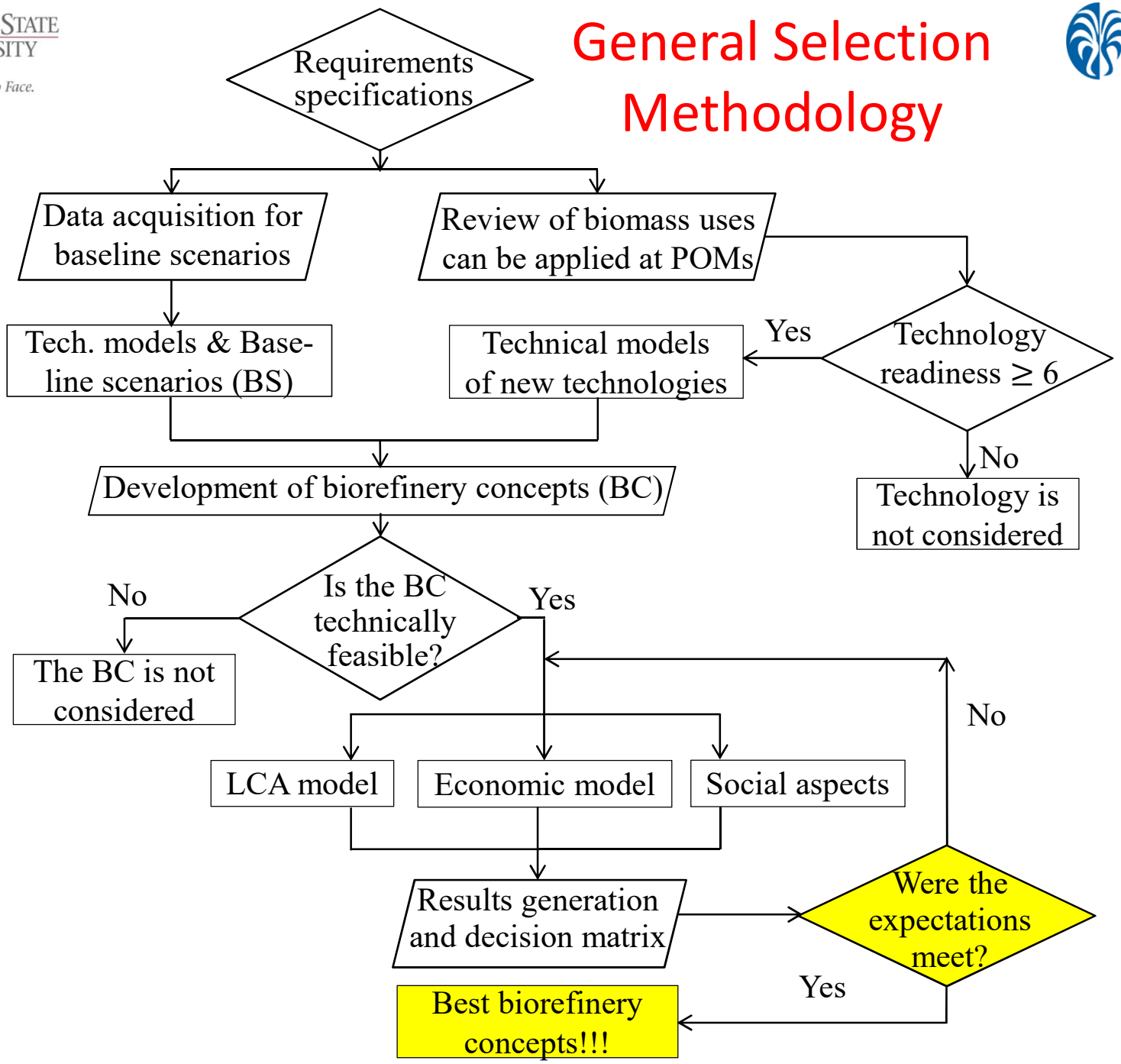
Results Generation (Normalization Process)



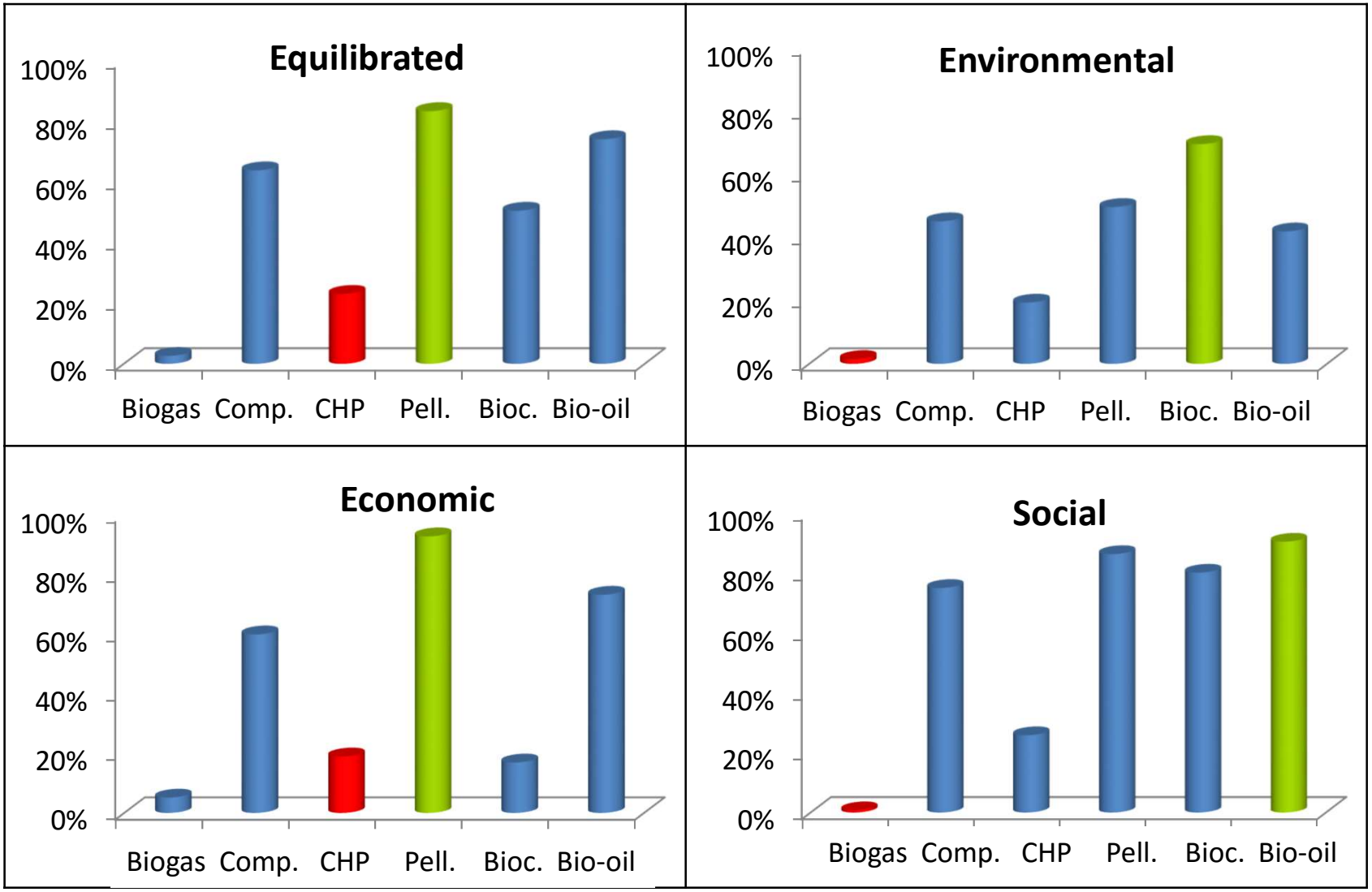
Choosing weighting factors

Categories	Equilibrated Scenario	Environmental Scenario	Economic Scenario	Social Scenario
Main Categories				
LCA (A)	33.3	80	10	10
Economic Ass. (B)	33.3	10	80	10
Social (C)	33.3	10	10	80
LCA				
GHG emissions (D)	33.3	60	60	60
EP (E)	33.3	20	20	20
NER (F)	33.3	20	20	20
Economic Ass.				
Extra Incomes (G)	33.3	60	60	60
NPV (H)	33.3	20	20	20
Payback Period (I)	33.3	20	20	20
Social				
New jobs (J)	50	60	60	60
Skills (K)	50	40	40	40

General Selection Methodology



Best Biorefinery Concepts!!!



Conclusions

1. The implementation of biorefinery concepts improves the environmental impacts on Carbon Footprint, Eutrophication Potential, and the Net Energy Ratio.

2. The methodology helps the stakeholders, the decision-makers and the policy-makers to choose different biorefinery options, taking into considerations specific site conditions by weighing values on environmental, economic and social impacts.

ACKNOWLEDGMENTS

WSU, Cenipalma, Oil Palm Promotion Fund (FFP), administrated by Fedepalma, POMs (Entrepalmas, Agroince, Morichal, Tequendama, Manuelita)


Thank you !
Questions?