National Technical University of Athens
Unit of Environmental Science and Technology

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# Valorization of industrial orange waste towards biofuel production

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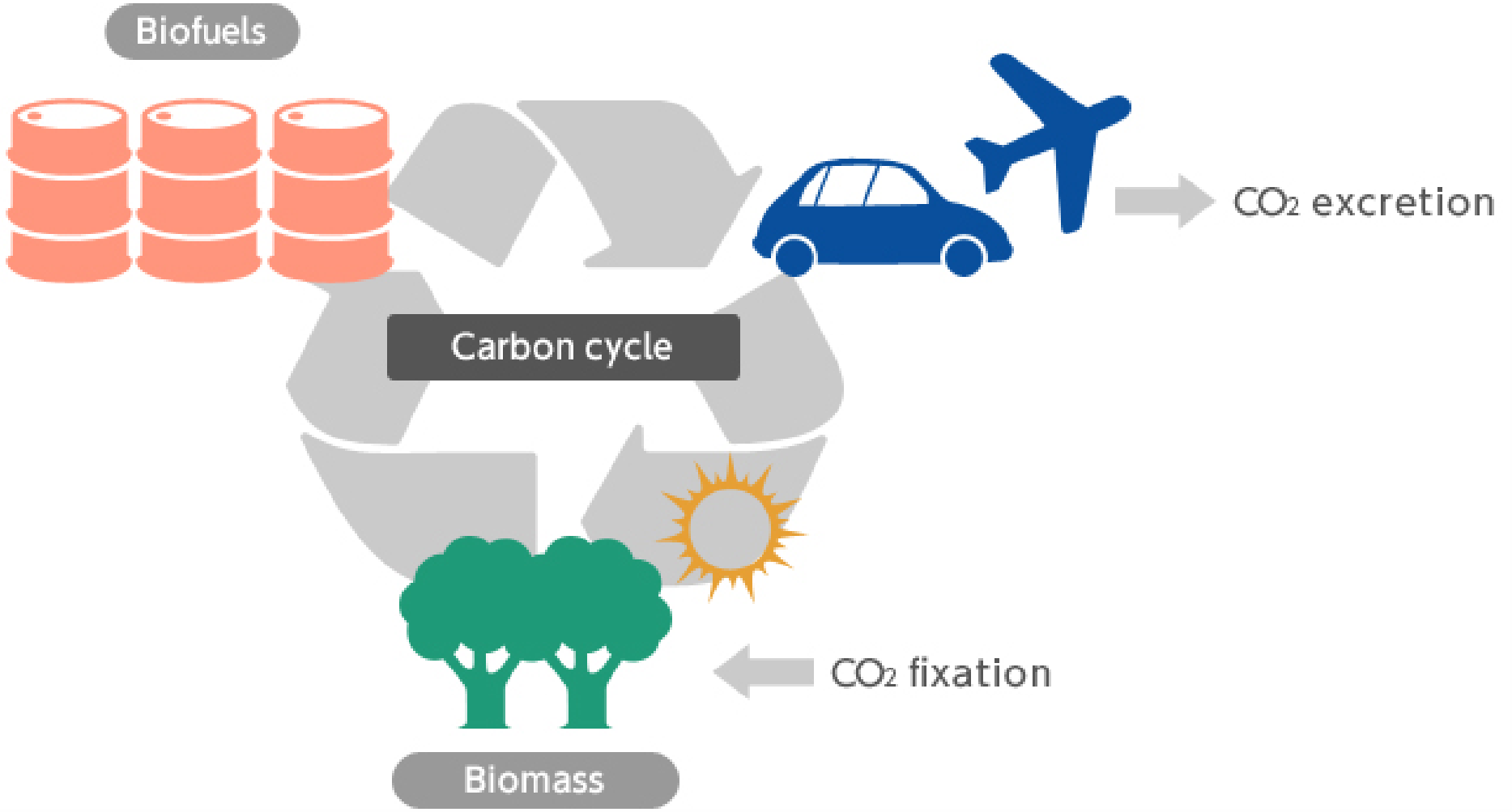
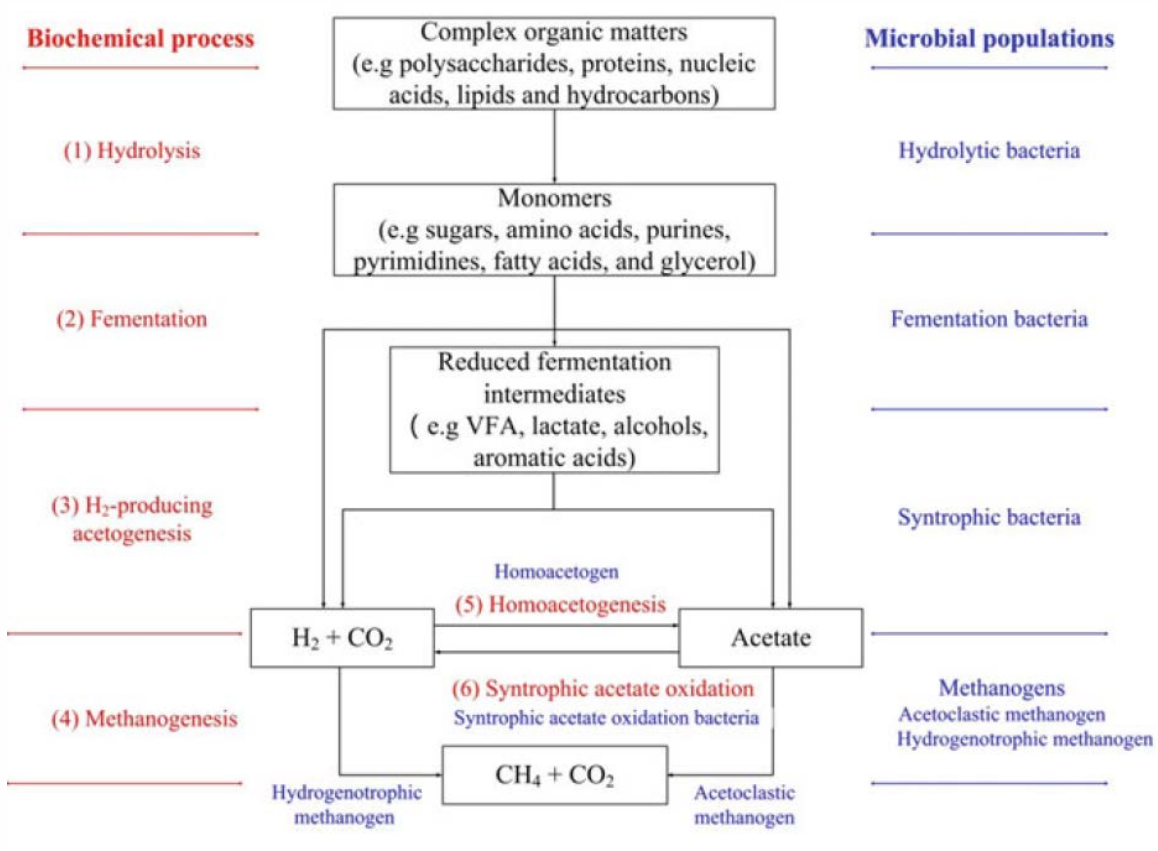
CIRCforBIO

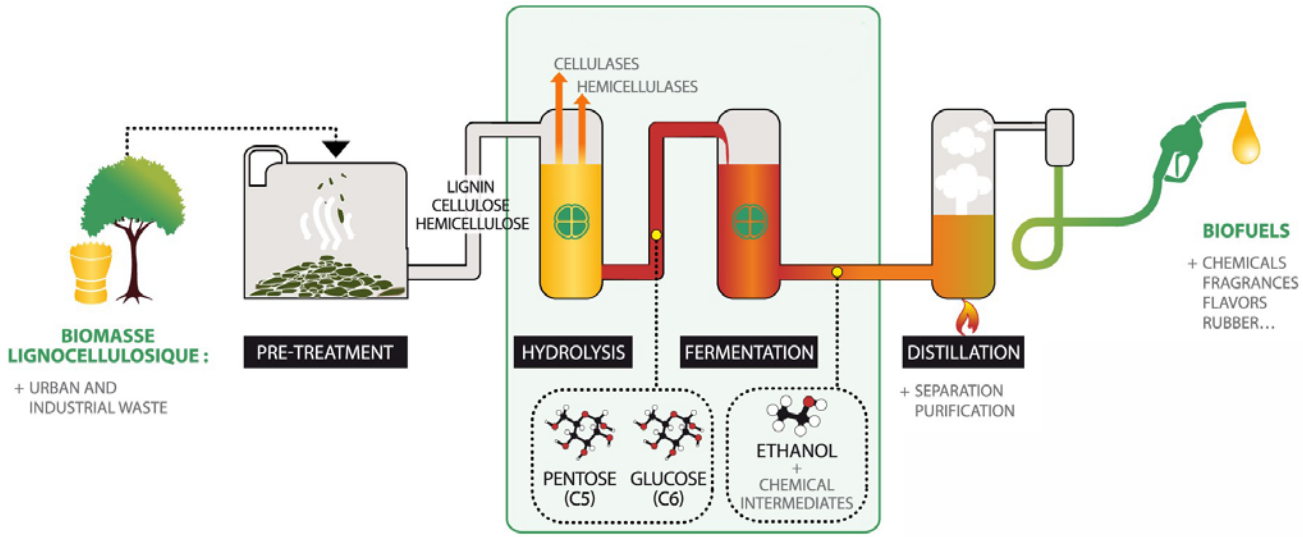
8th International Conference on Sustainable Solid Waste Management


Biofuels
$CO_2$ excretion
Carbon cycle
$CO_2$ fixation
Biomass

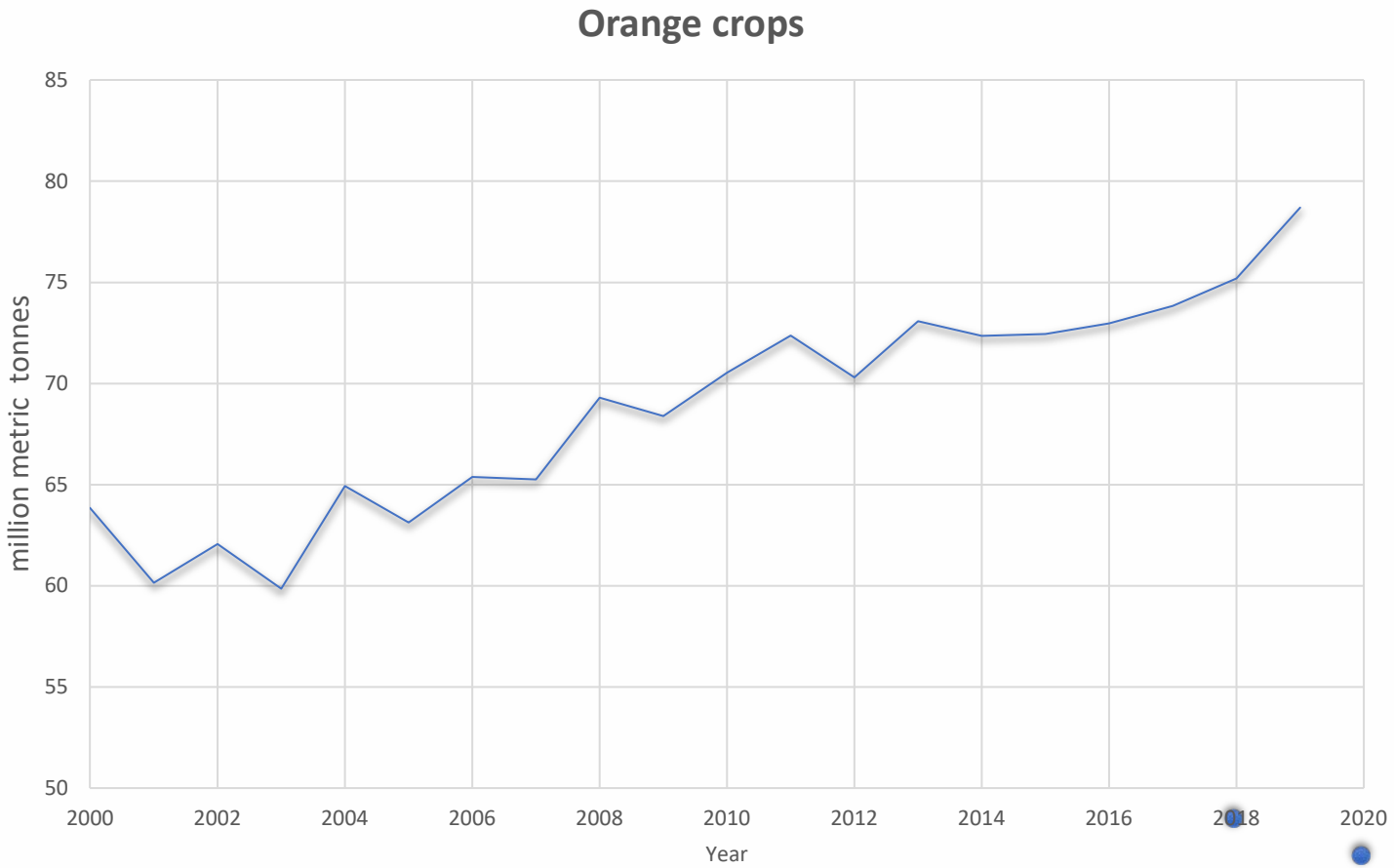
## Anaerobic Digestion

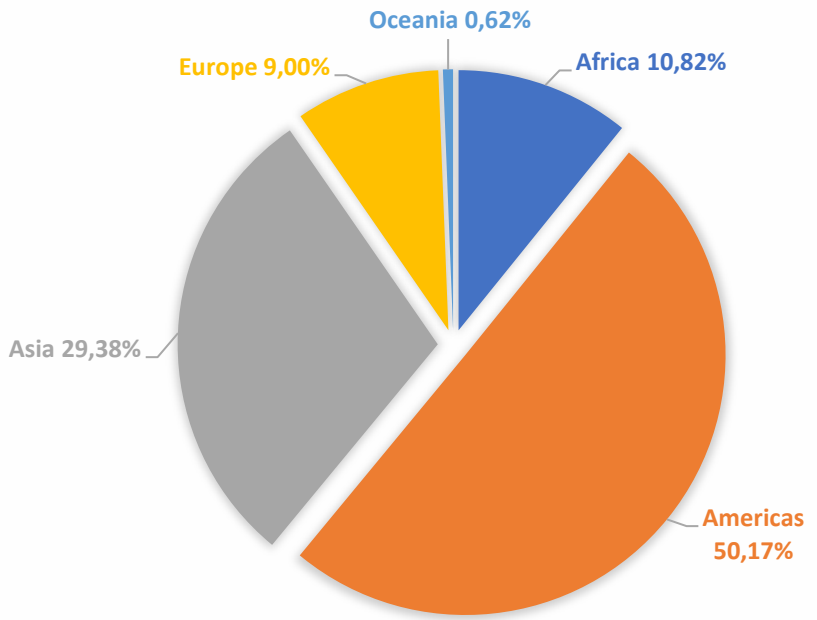



## Alcoholic Fermentation



**Orange fruits**: 49.8% of the total citrus production worldwide




*Source: Food and Agriculture Organisation*

**36%** of total production processed by industry

**Orange fruit**
- 55-65% Peel
- 4-5% Pulp
- 30-40% Juice

**Orange waste**
- 80-90% moisture content

**Common uses:**
- Animal Feed
- Landfill

*Sources: Ángel Siles López, J., Li, Q. and Thompson, I.P., 2010. Biorefinery of waste orange peel. Critical reviews in biotechnology, 30(1), pp.63-69.*
*USDA—United States Department of Agriculture. Foreign Agricultural Service. Citrus: World Markets and Trade. 2019; pp. 1–11. Available online: https://apps.fas.usda.gov/psdonline/circulars/citrus.pdf (accessed on 25 July 2019).*

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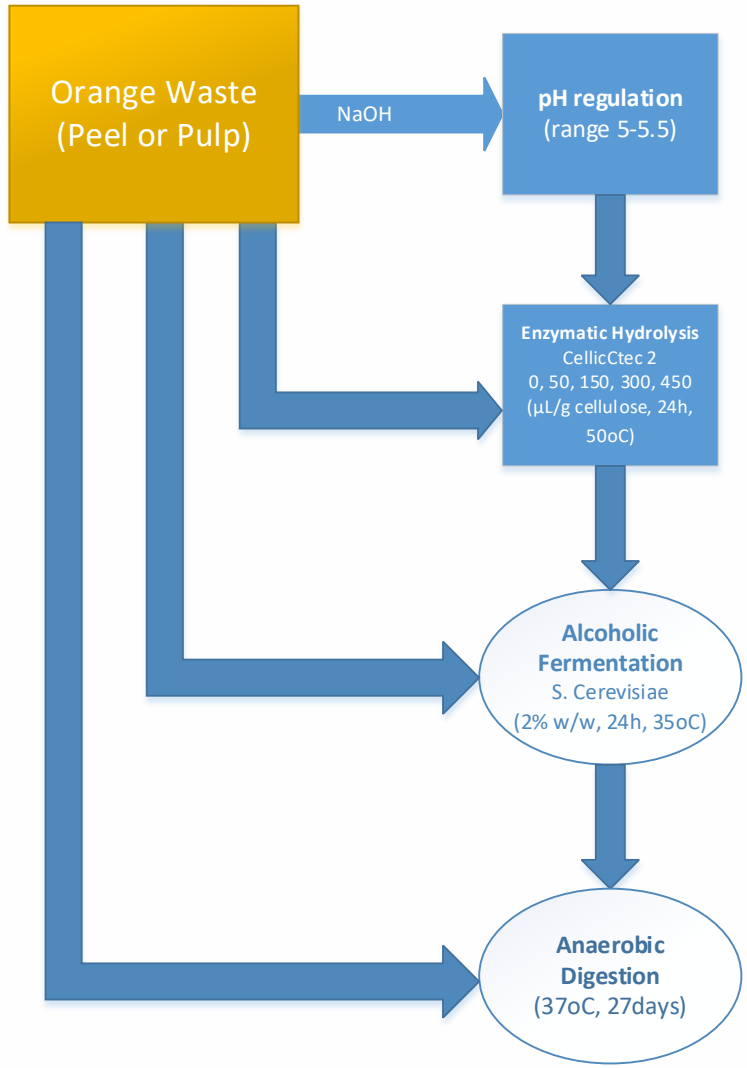
## Chemical Composition

| Parameter | Orange Peel Waste | Orange Pulp Waste |
|---|---|---|
| **Total Solids, TS (%)** | 97.2 ± 0.20 | 98.45 ± 0.15 |
| **Liquid Phase** | | |
| **Total Carbon, TC (mg/L)** | 4542.00 ± 49.60 | 2673 ± 16 |
| **Total inorganic carbon, TIC (mg/L)** | 0.25 ± 0.05 | 0.2 ± 0.11 |
| **Total Organic Carbon, TOC (mg/L)** | 4542.00 ± 50.00 | 2673 ± 17 |
| **Total Nitrogen, TN (mg/L)** | 68.27 ± 6.05 | 54.50 ± 0.37 |
| **Free Sugars(% d.b.)** | 4.70 ± 0.10 | 1.65 ± 0.23 |
| **Solid Phase** | | |
| **Volatile Solids, VS (% d.b.)** | 96.80 ± 0.10 | 97.15 ± 0.05 |
| **Water Soluble Solids, WSS (% d.b.)** | 38.34 ± 0.04 | 22.41 ± 0.10 |
| **Cellulose (% d.b.)** | 13.87 ± 0.76 | 24.86 ± 2.07 |
| **Hemicellulose (% d.b.)** | 31.70 ± 1.12 | 33.76 ± 1.33 |
| **Starch (% d.b.)** | 1.02 ± 0.26 | 3.16 ± 0.46 |
| **Acid Soluble Lignin, ASL (% d.b.)** | 1.72 ± 0.18 | 3.55 ± 0.12 |
| **Acid Insoluble Residue, AIR (% d.b.)** | 17.12 ± 0.21 | 19.90 ± 0.17 |

## Experimental design of alcoholic fermentation



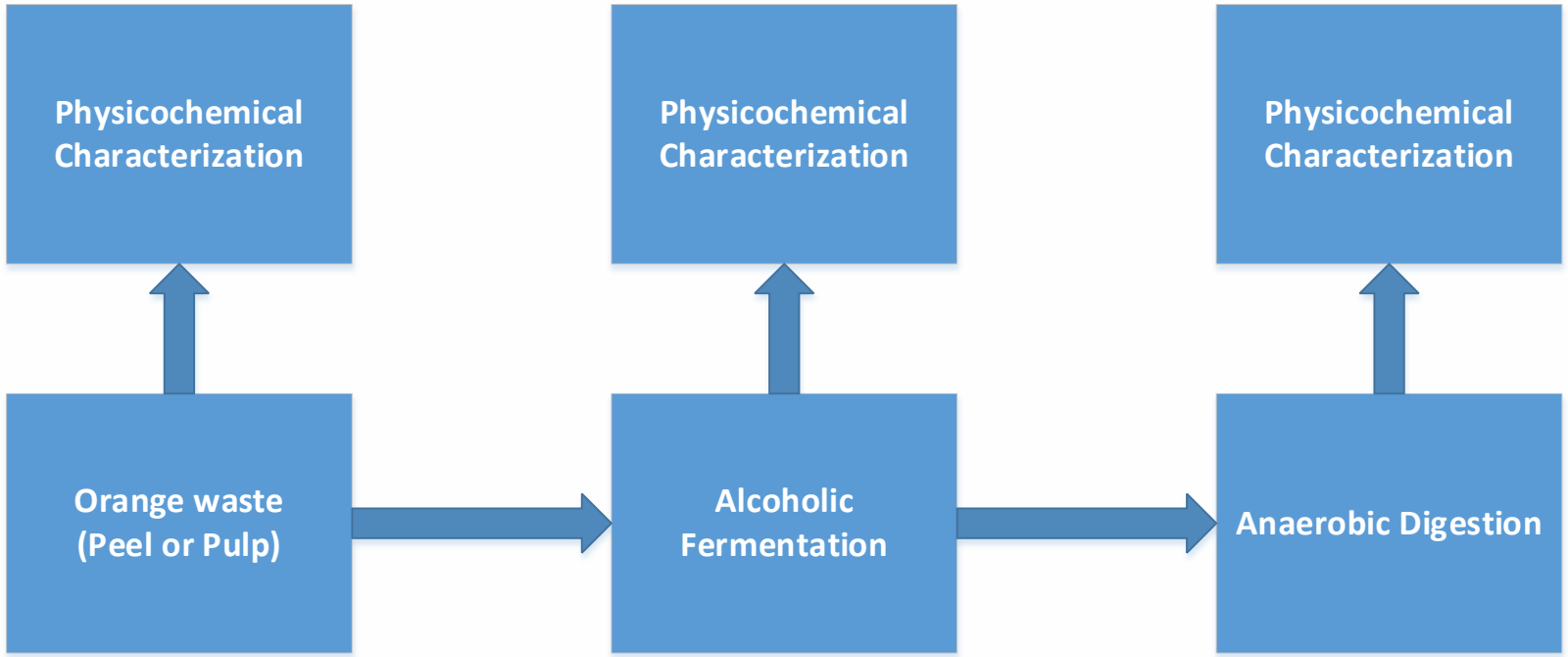
## Physicochemical Characterization

Solid Phase:

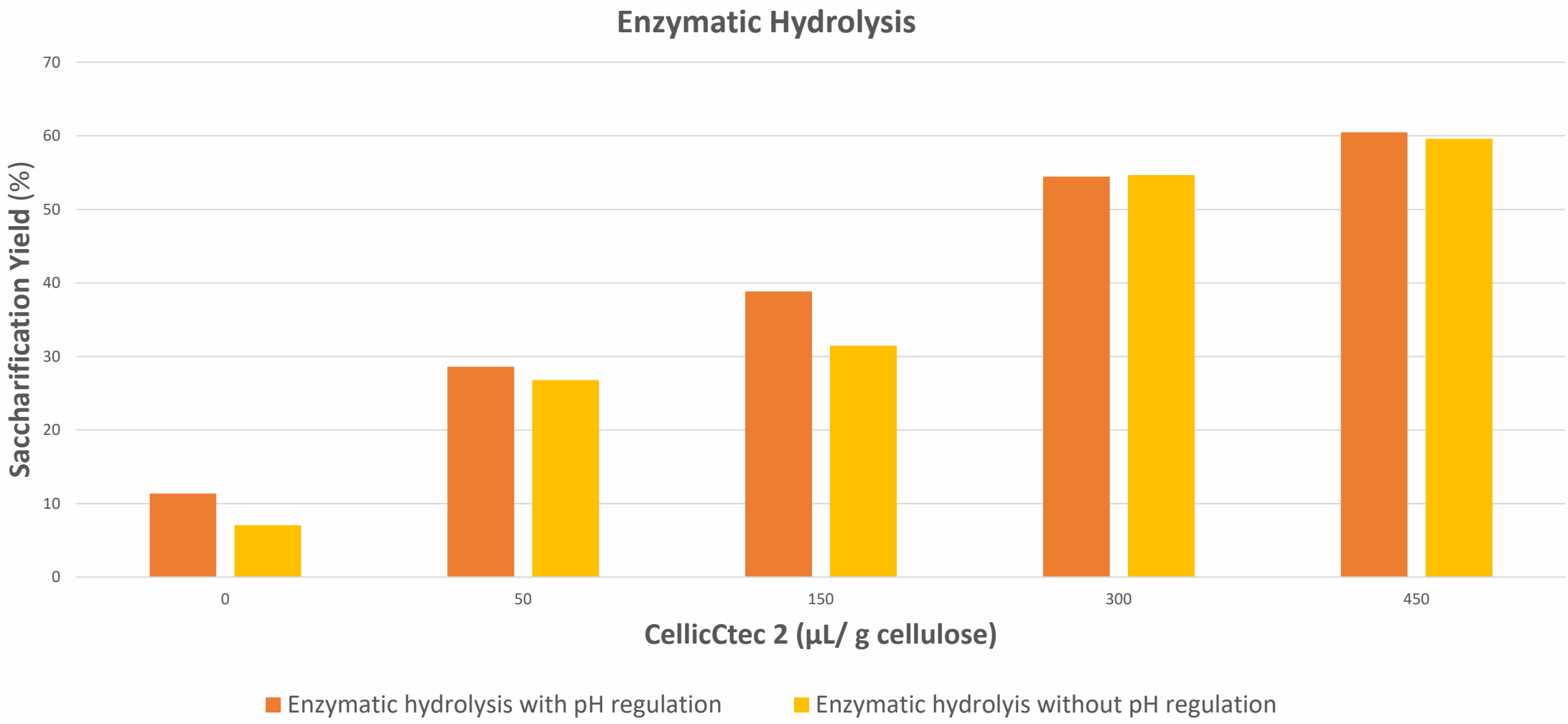
- Total Solids (TS)
- Water Soluble Solids (WSS)
- Volatile Solids (VS)
- Cellulose (Cel)
- Hemicellulose (HCel)
- Starch (STA)
- Soluble Lignin (ASL)
- Acid Insoluble Residue (AIL)

Liquid Phase:

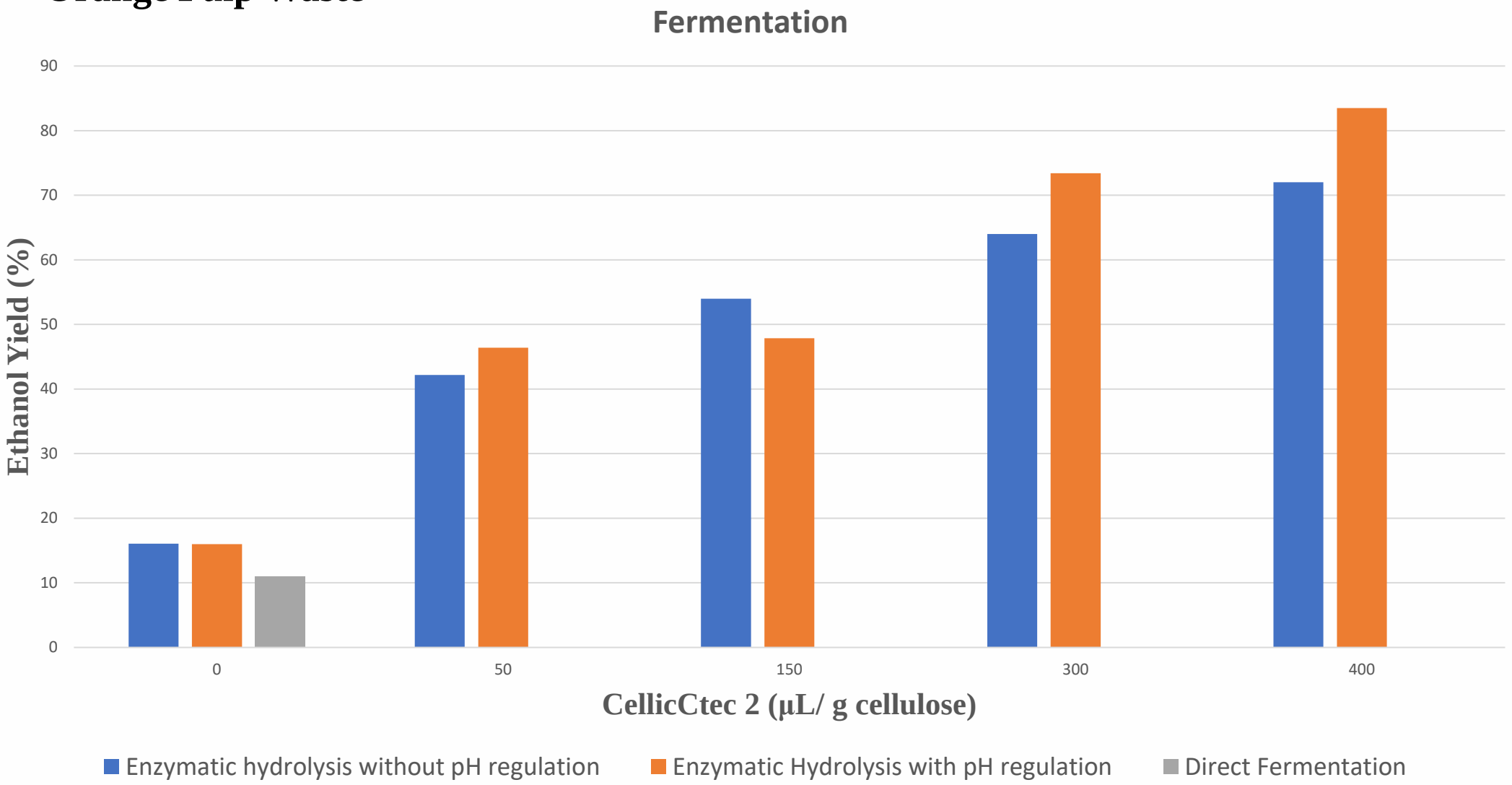
- Total Organic Carbon (TOC)
- Total Nitrogen (TN)
- Volatile Fatty Acids (VFAs)



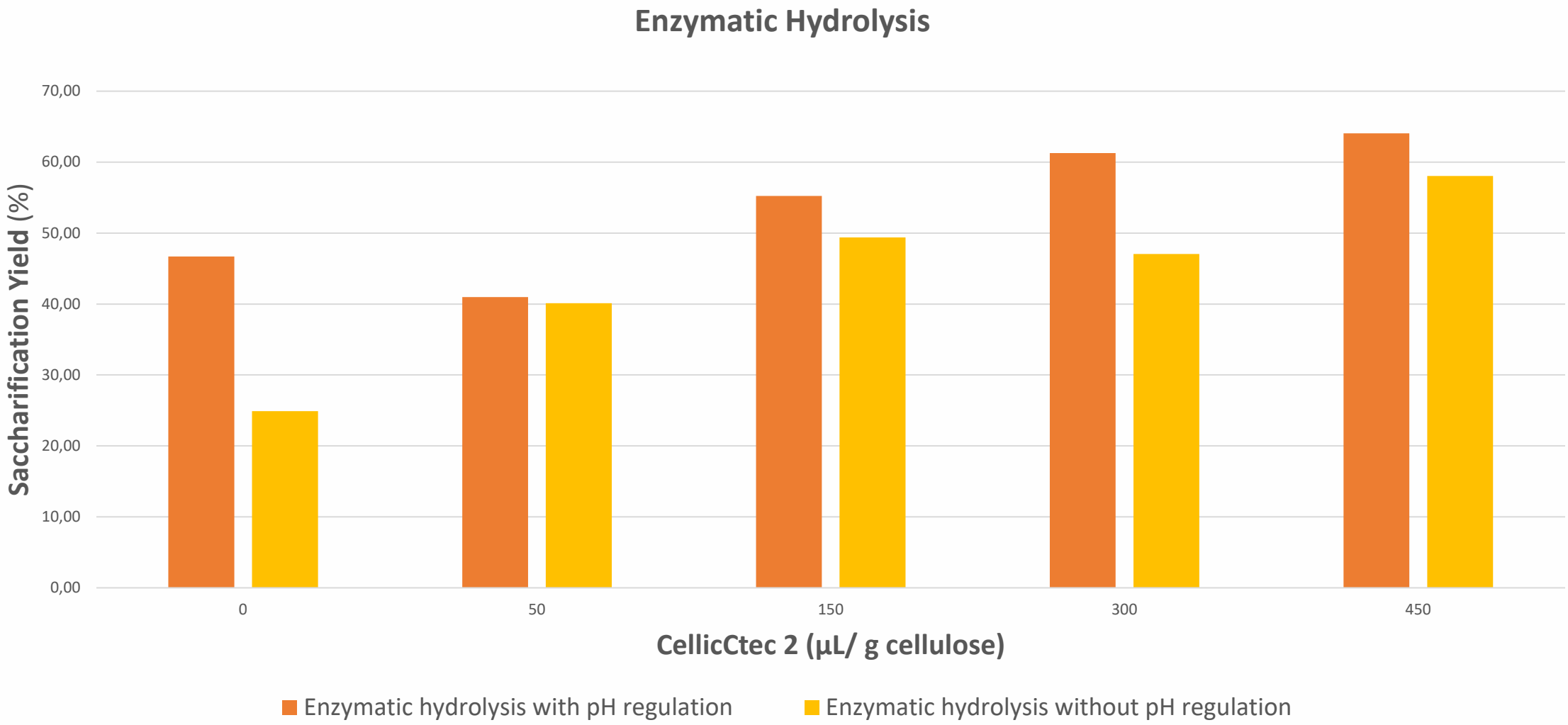
# Orange Pulp Waste



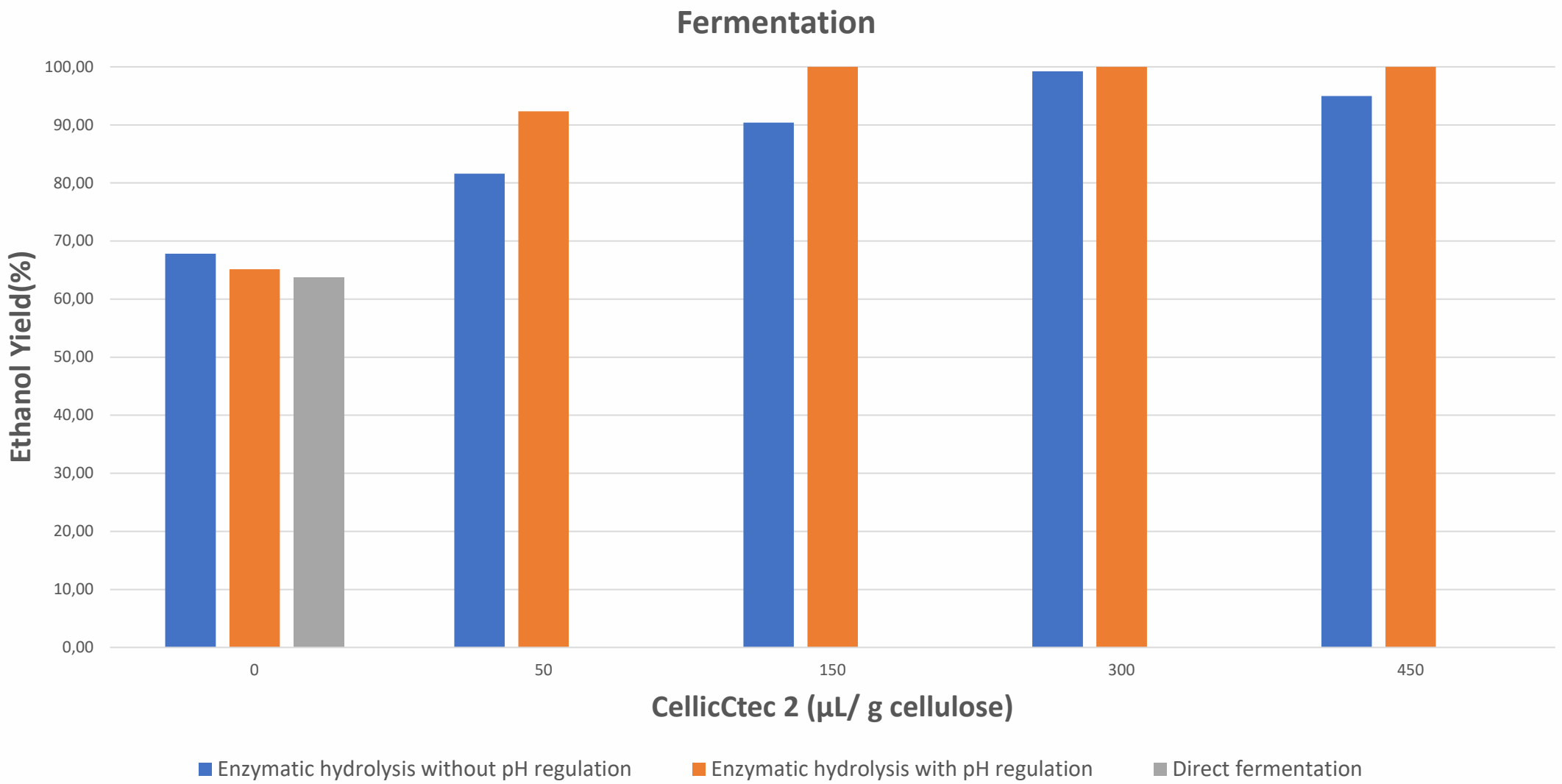
# Orange Pulp Waste



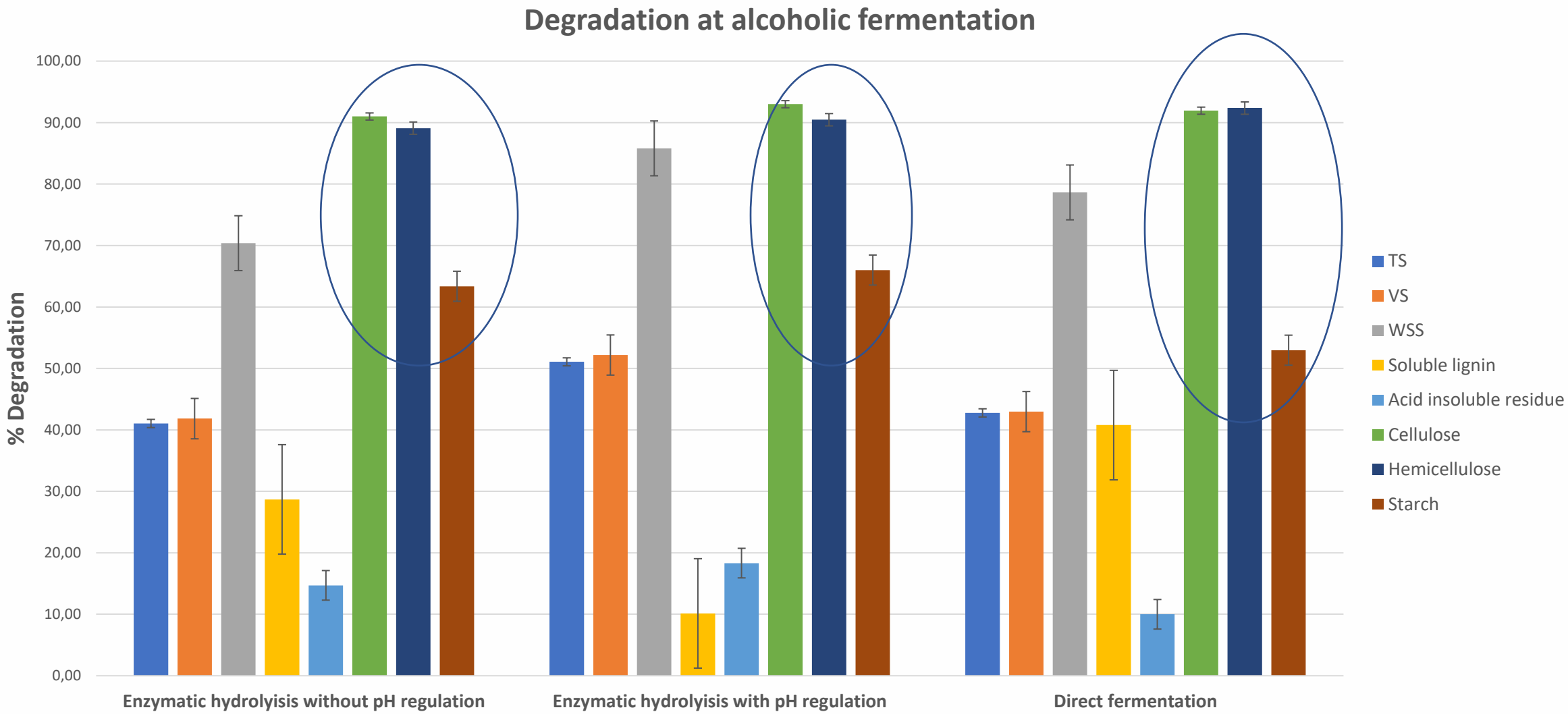
# Orange Peel Waste



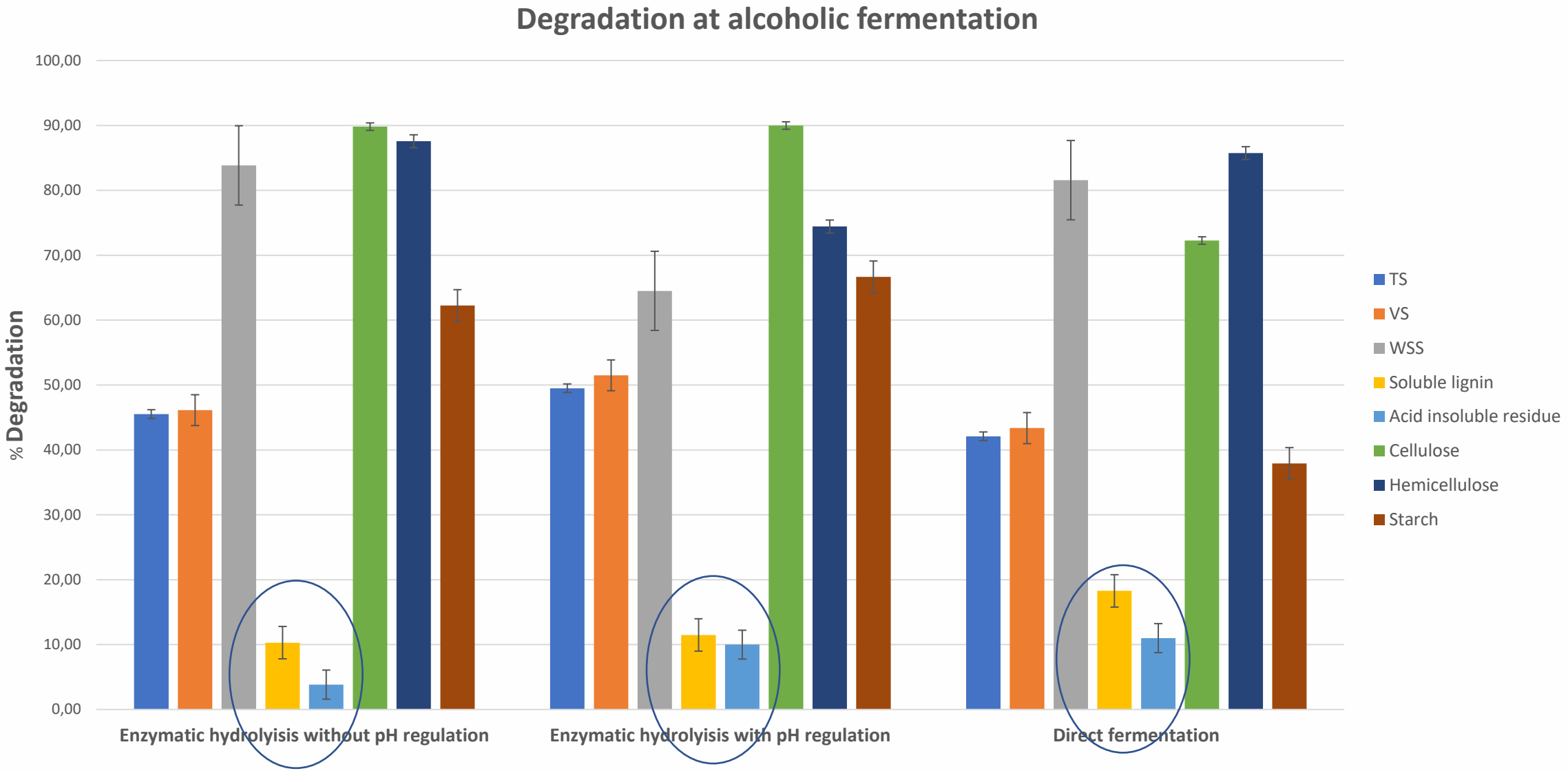
# Orange Peel Waste

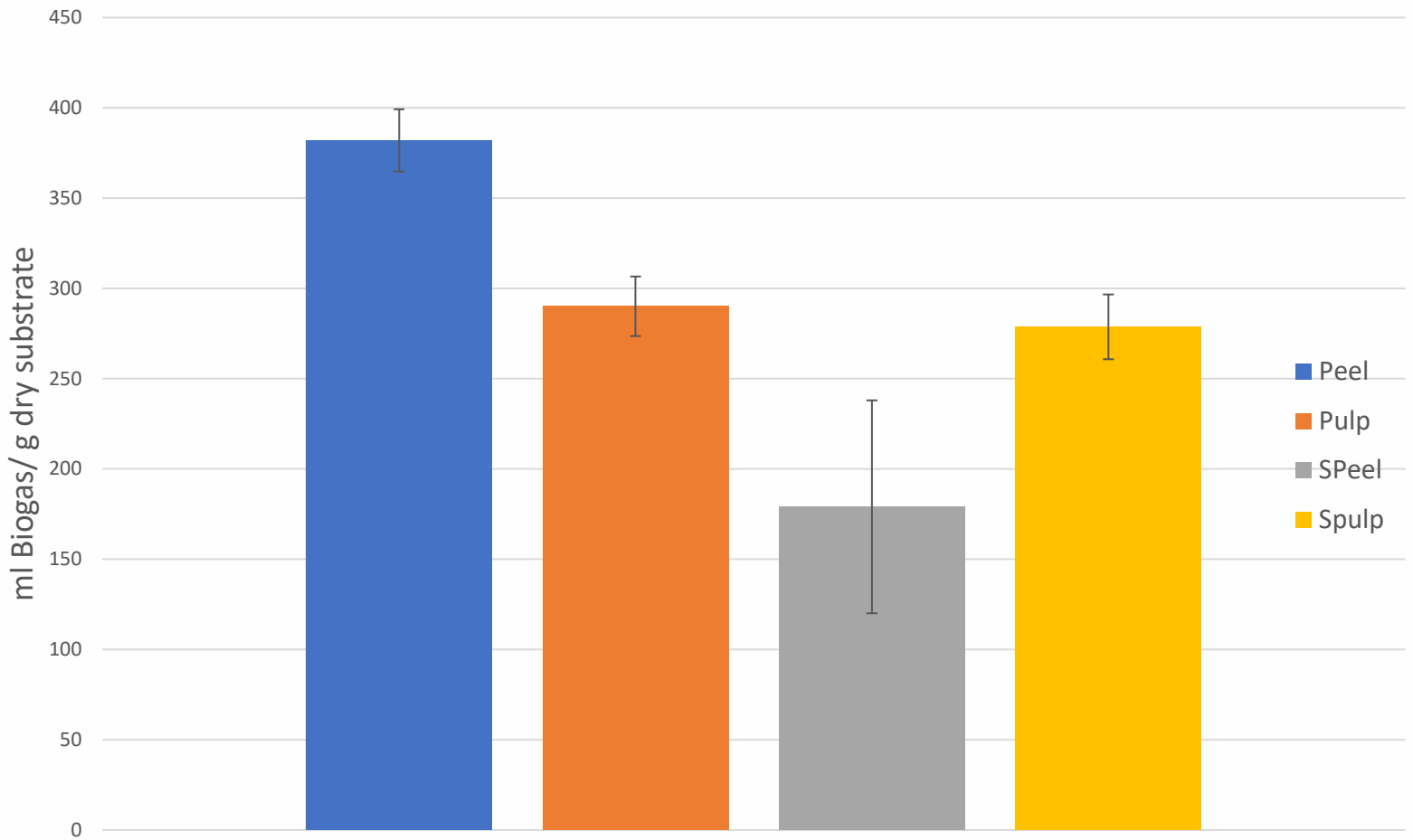


# Orange Pulp Waste



# Orange Peel Waste






**mL Biogas/ g dry substrate**

Orange peel: 382.0 ± 17.2

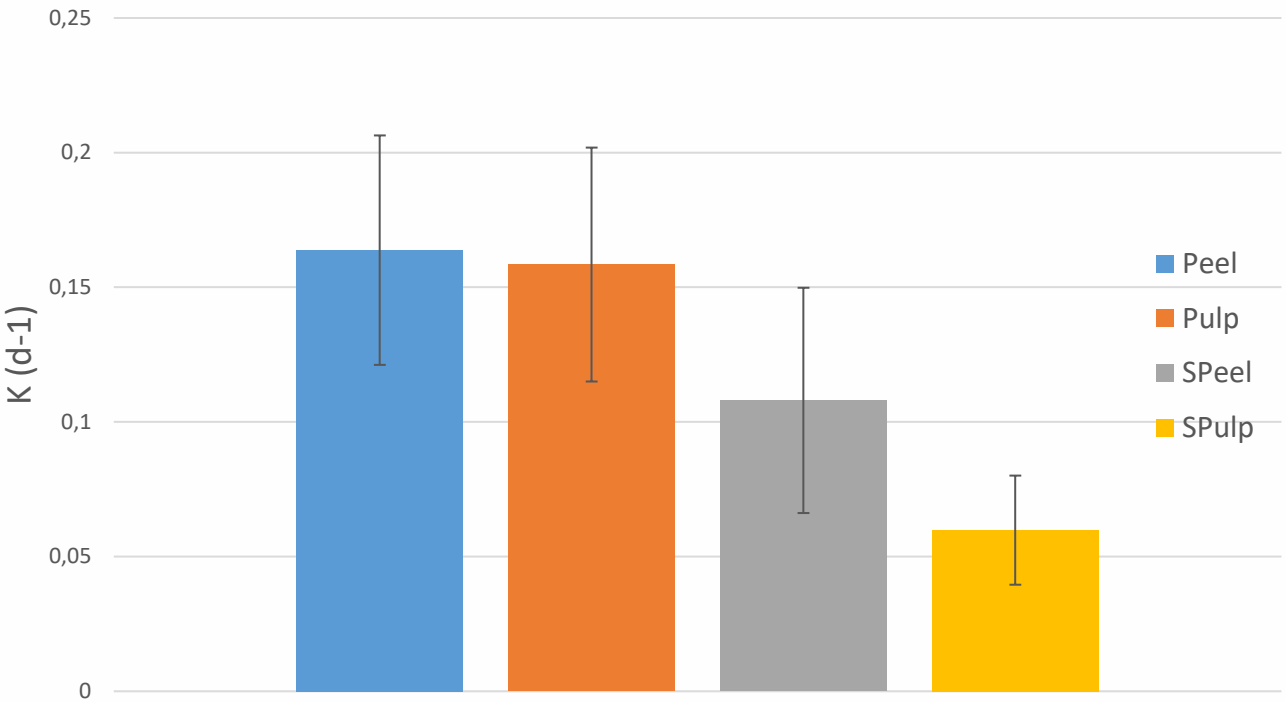
Orange pulp: 290.2 ± 16.5

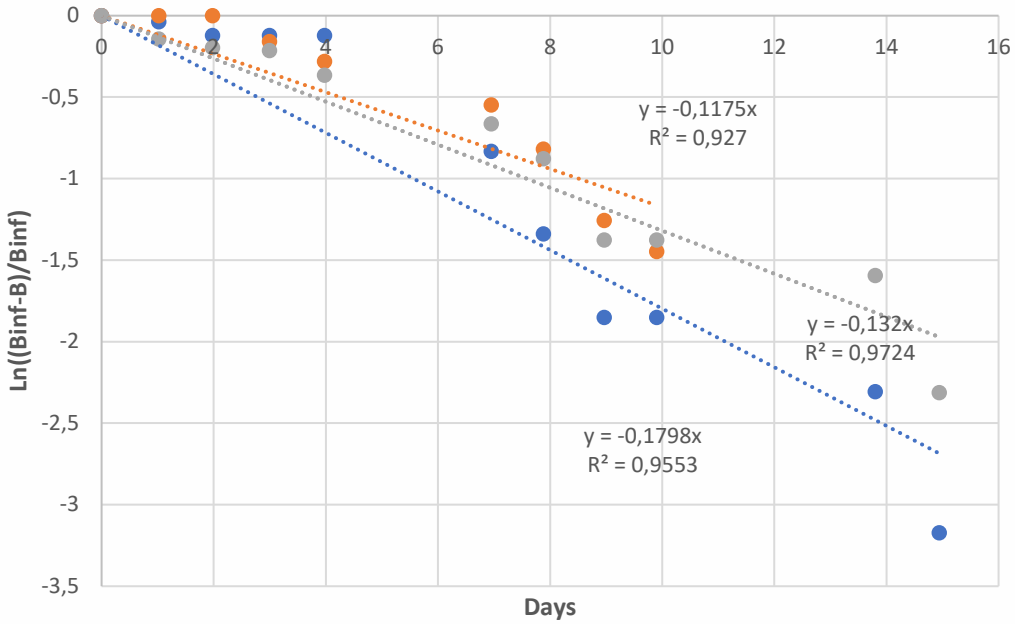
Stillage peel: 179.4 ± 59.0

Stillage pulp: 271.0 ± 18.0

# 1st order kinetics

$$\frac{dS}{dT} = -kS \qquad ln\frac{Binf - B}{Binf} = -kt$$




## K (d-1)

**Peel**: 0.16 ± 0.043

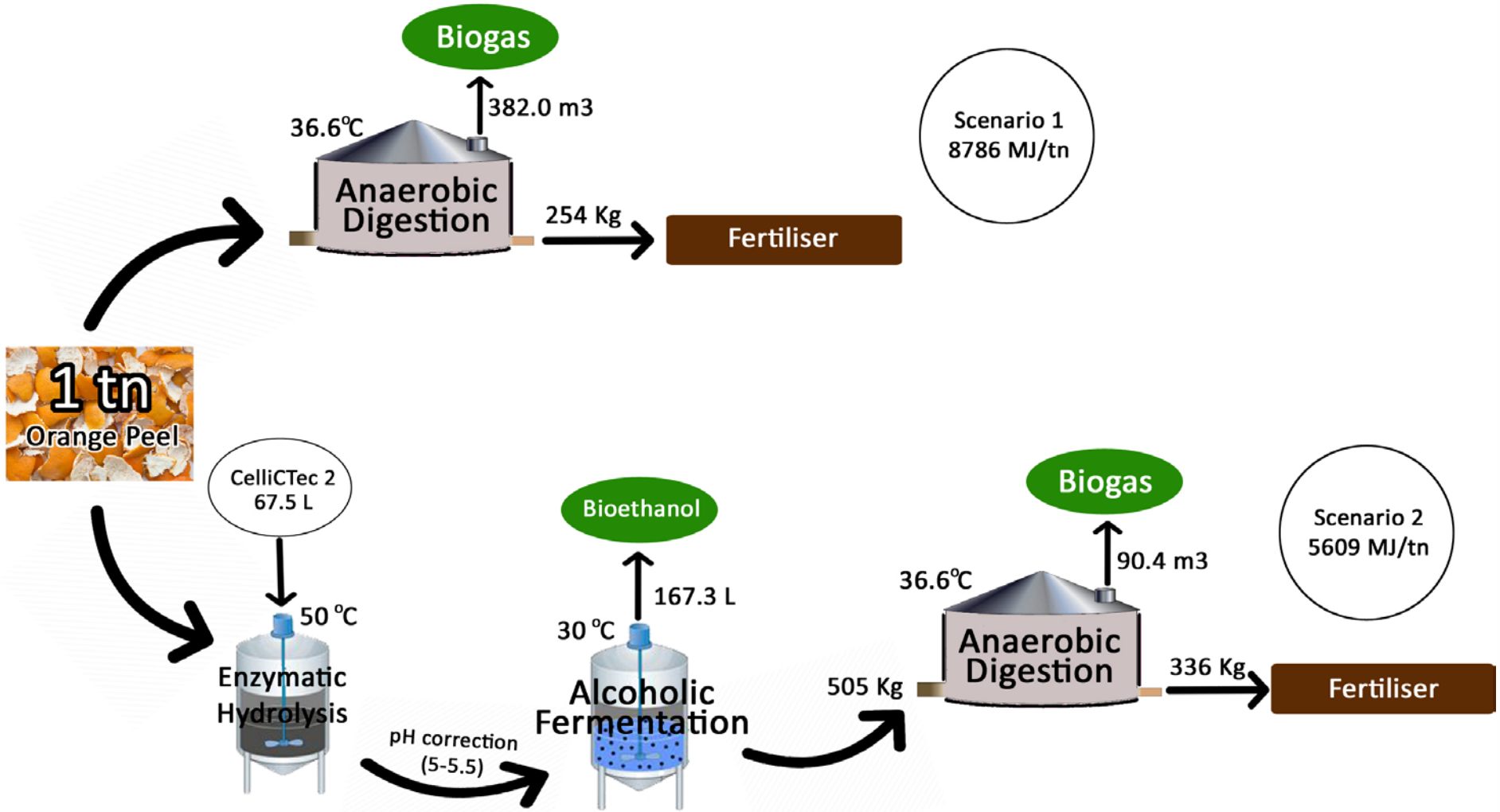
**Pulp**: 0.155 ± 0.041

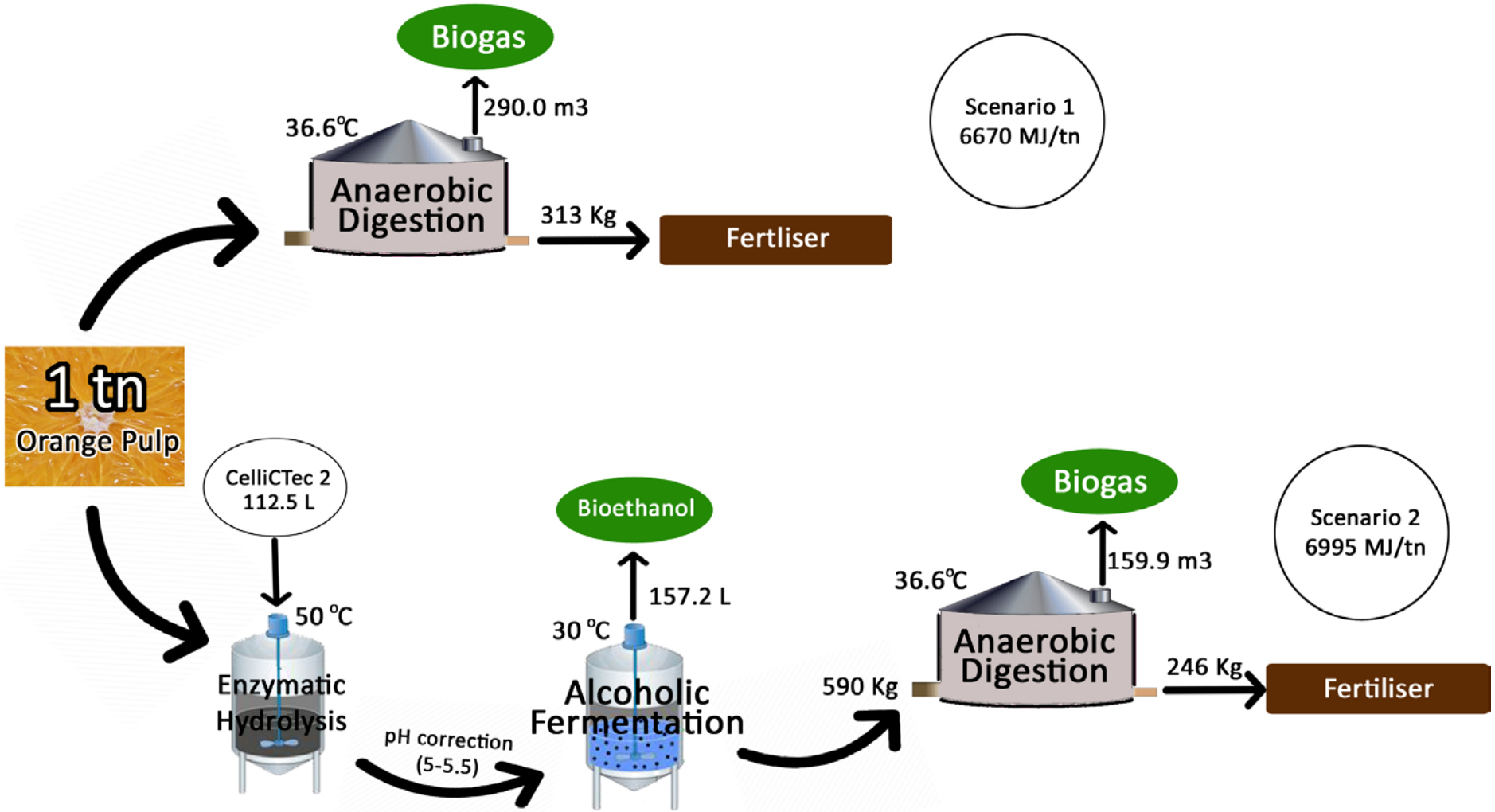
**Stillage Peel**: 0.11 ± 0.039(Reduction 31.3%)

**Stillage Pulp**: 0.06 ± 0.02 (Reduction 61.2%)

# Anaerobic Digestion Degradability

| | Pulp | Stillage Pulp | Peel | Stillage Peel |
|---|---|---|---|---|
| **Liquid Phase** | | | | |
| %TOC | 87.92 ± 5.00 | 36.19 ± 22.86 | 100 ± 0 | 62.36 ± 11.51 |
| % TN | 96.95 ± 6.83 | 68.10 ± 30.00 | 47.11 ± 6.48 | 61.96 ± 20.28 |
| **Solid Phase** | | | | |
| % VS | 65.20 ± 12.83 | 63.70 ± 11.61 | 73.01 ± 8.29 | 69.63 ± 12.18 |
| % Cellulose | 98.95 ± 2.34 | 63.60 ± 17.42 | 94.51 ± 8.77 | 79.26 ± 32.57 |
| % Hemicellulose | 94.64 ± 0.79 | 97.02 ± 3.38 | 96.46 ± 2.27 | 92.67 ± 12.27 |
| % Starch | 100 ± 0 | 100 ± 0 | 100 ± 0 | 100 ± 0 |
| % Soluble Lignin | 66.48 ± 9.65 | 81.17 ± 4.61 | 52.79 ± 9.80 | 74.57 ± 6.84 |


Biogas
382.0 m3
36.6℃
Anaerobic Digestion
254 Kg
Fertiliser
Scenario 1
8786 MJ/tn
1 tn
Orange Peel
CelliCTec 2
67.5 L
50 ℃
Enzymatic Hydrolysis
pH correction
(5-5.5)
Bioethanol
167.3 L
30 ℃
Alcoholic Fermentation
505 Kg
Biogas
90.4 m3
36.6℃
Anaerobic Digestion
336 Kg
Fertiliser
Scenario 2
5609 MJ/tn


Biogas
290.0 m3
36.6℃
Anaerobic Digestion
313 Kg
Fertliser
Scenario 1
6670 MJ/tn
1 tn
Orange Pulp
CelliCTec 2
112.5 L
50 ℃
Enzymatic Hydrolysis
pH correction
(5-5.5)
Bioethanol
157.2 L
30 ℃
Alcoholic Fermentation
590 Kg
Biogas
159.9 m3
36.6℃
Anaerobic Digestion
246 Kg
Fertiliser
Scenario 2
6995 MJ/tn

# Conclusions

**Combination** of anaerobic digestion and alcoholic fermentation

- For **orange peel** concentration of bioethanol 13.2 g/L (CellicCTec2 450 μL / g cellulose, S. Cerevisiae 2%, 24 hours fermentation) in a yield of almost 100% as well as a maximum amount of biogas 179.0 ± 59.0 mL / g waste.
- Waste mass reduction 66.4%.
- For **orange pulp** bioethanol concentration 12.4 g / L (CellicCTec2 450 μL / g cellulose, S. Cerevisiae 2%, 24 hours fermentation) at a yield of 83.5% and a maximum amount of biogas 271.0 ± 18.0 mL / g waste.
- Waste mass reduction 75.4%.

**Direct** anaerobic digestion

- For **orange peel** biogas production 382.0 ± 17.2 mL / g waste.
- Waste mass reduction 74.6%.
- For **orange pulp** biogas production 289.71 ± 16.5 mL / g waste.
- Waste mass reduction 68.7%.

# Further actions

- Techno-economical evaluation of the procedures
- Optimisation of the conditions at the processes
- Examination of the orange waste without drying of the raw material
- Extraction of other added-value products such as essential oils, pectins and terpenes.
- Convert via biochemical processes to other value added substances such as enzymes

# Thanks for your attention

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