A techno-economic assessment of bioethanol production from switchgrass through biomass gasification and syngas fermentation

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Background

Problem

According to the EIA the **global energy demand is expected to rise** by 47% in the next 30 years and in the same time frame the liquid fuel consumption is assumed to increase by 64% compared to 2020 levels [1]. Fossil fuels cannot meet the ever-increasing demands because they are not economically and environmentally sustainable.

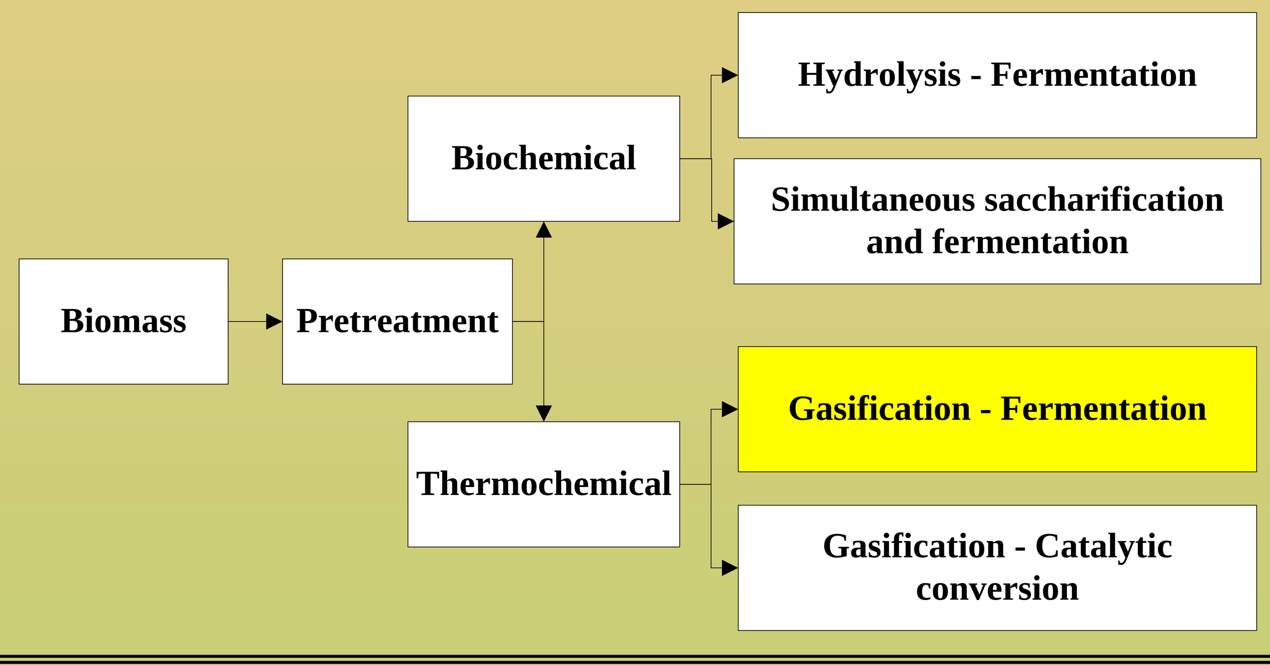
Possible solution

In a context where the time available is too short to eliminate the need for carbon-based fuels, the solution may be to increase the production of **biofuels**. While several types of resources, such as solar, wind, hydropower, and geothermal energy, can be utilized to produce energy and heat, biomass is the sole resource that can also produce chemicals and materials. In addition to fossil fuels, biomass is the sole carbon-rich resource on the planet [2]. From 2020 to 2025, the worldwide **bioethanol** market is expected to increase at a CAGR of 14.0%.

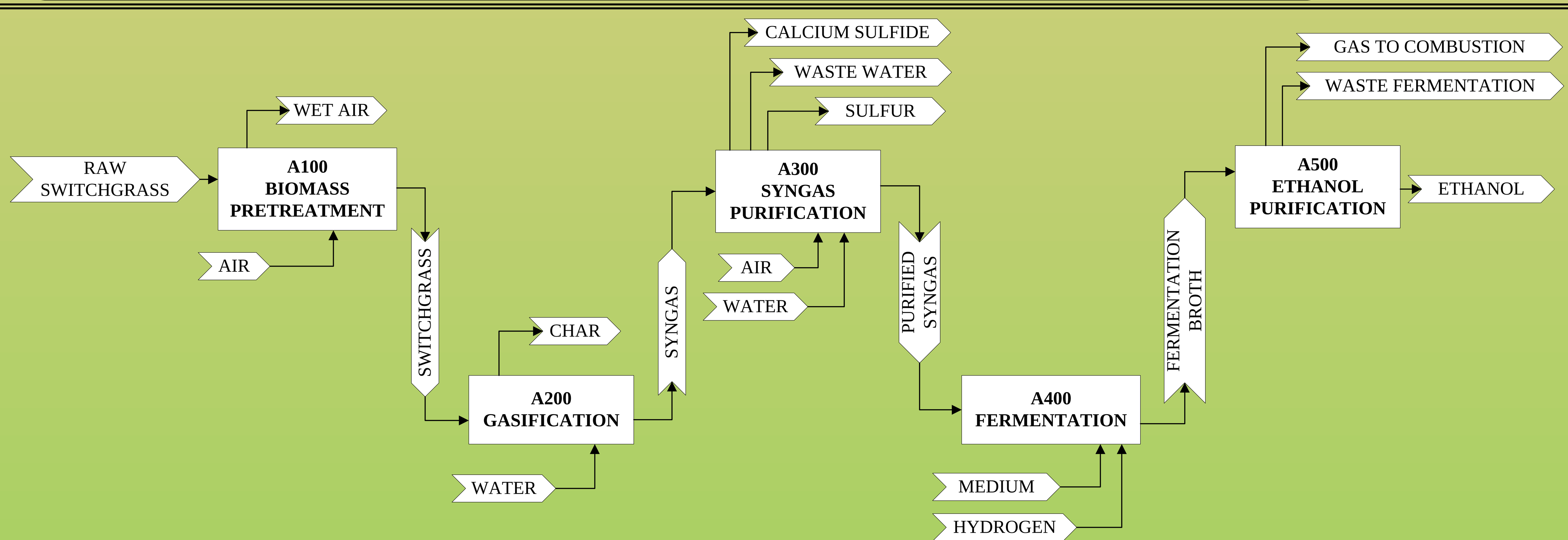
In this study

a system design for bioethanol production from switchgrass using gasification and syngas fermentation is proposed. The goal of the work is to increase the amount of ethanol produced per tonne of biomass. Additionally, a financial model was built to estimate the capital expenditure, the operating costs, and the minimum ethanol selling price through a discounted cash flow analysis.

Different process routes for ethanol production



Process Overview



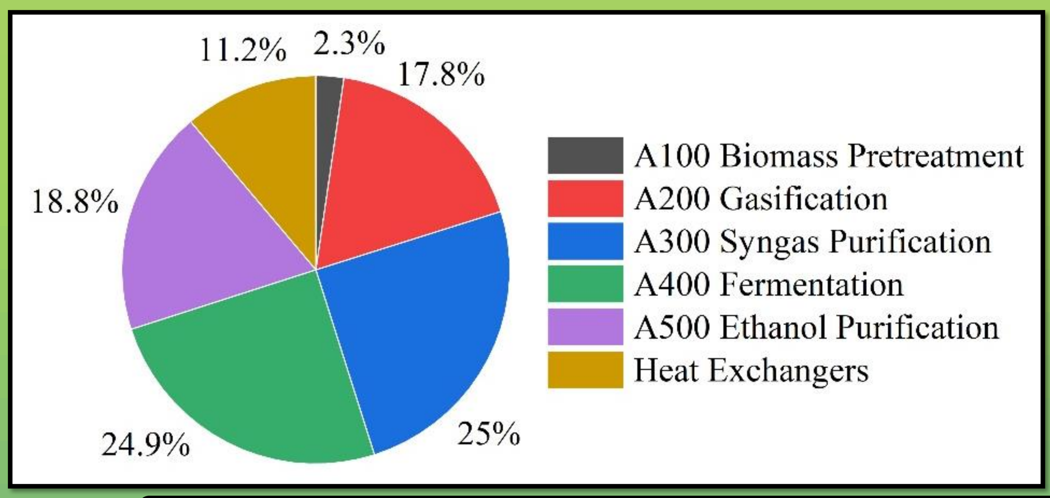
Aspen Plus® was used to develop and simulate a comprehensive and integrated **process flowsheet** ranging from switchgrass to ethanol.

Important issues were addressed, such as:

- the study of the optimal gasification conditions to produce a syngas composition optimal for the fermenter;
- an accurate purification of the synthesis gas;
- the realistic design of the bioreactors;
- the consideration of the nutrients necessary for the bacteria both as regards their removal from ethanol and the costs per liter of medium.

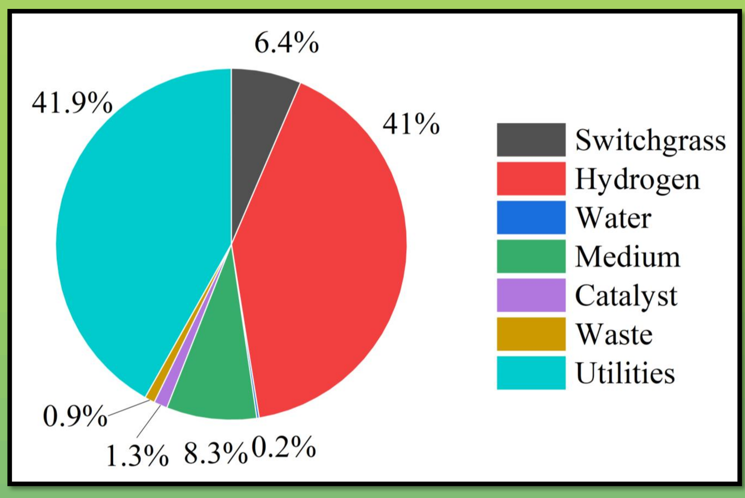
Process Economics

Total Project Investment



Breakdown of the **equipment cost** between the different sections of the plant. The section with the higher costs of the equipment is the purification of the syngas.

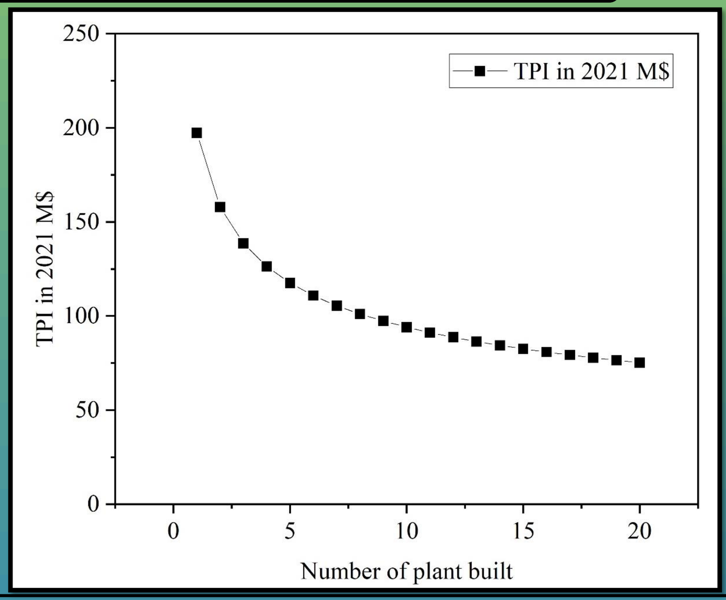
Variable Operating Costs



Distribution of the variable operating costs. As the size of the plant increases, the variable operating costs consequently increase, among which the most significant are linked to hydrogen and utilities. However, before 2050 it is possible to estimate a reduction of about 75% in the costs of green hydrogen [3].

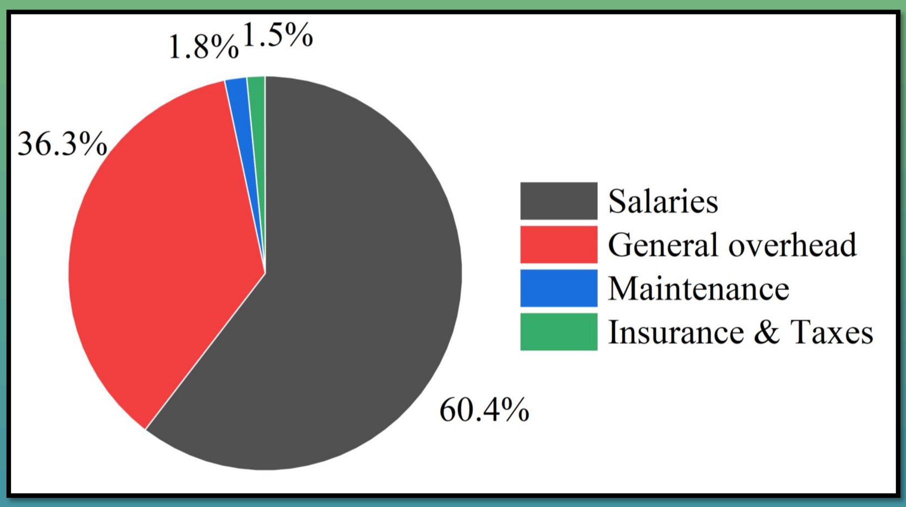
Potential savings of building more plants.

Learning curve effect on the pioneer Total Project Investment (TPI) considering 750000 tonne/year switchgrass as plant scale. It is possible to see a 48% reduction in TPI at the tenth built plant.



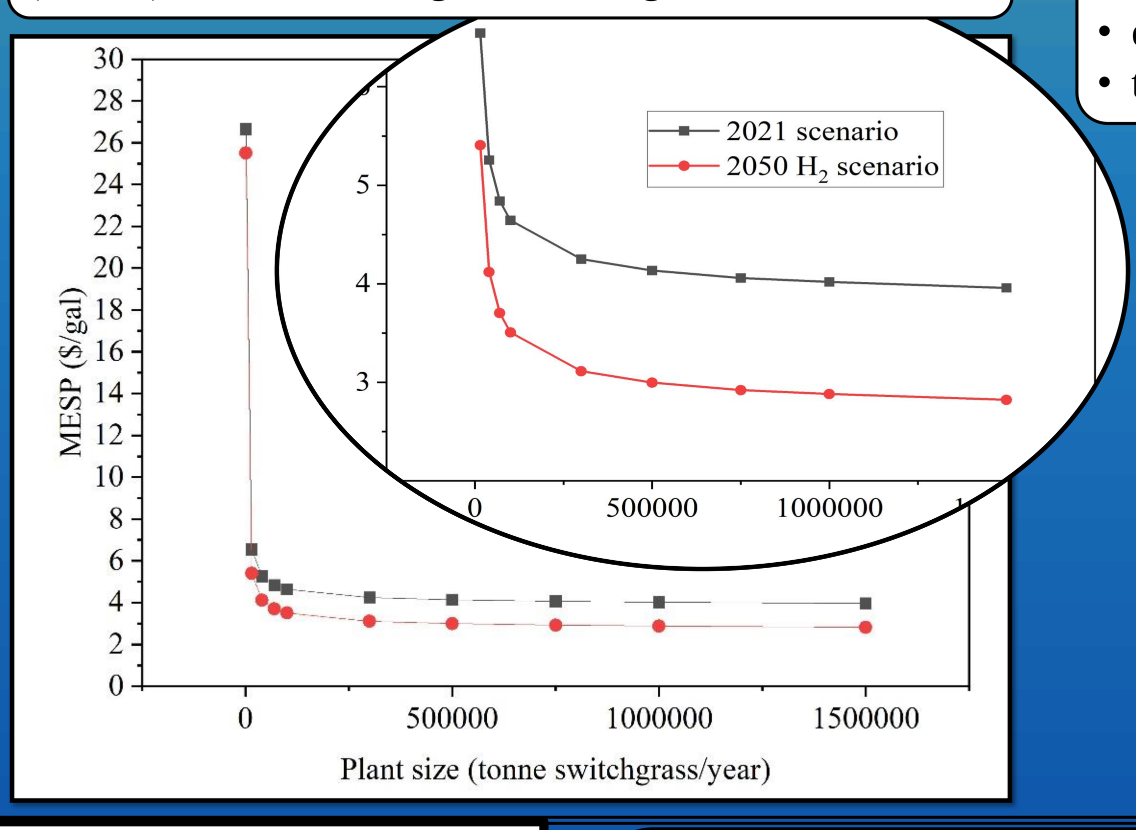
Fixed operating costs

Distribution of the fixed operating costs. Whether the plant is working at full capacity or not, the whole fixed operating costs are charged.



Results

Effect of plant size on minimum ethanol selling price (MESP) non considering the learning effect.



A considerable **ethanol yield** of 268.1 gal/tonne switchgrass was reached:

- enriching the syngas with green H_2;
- thanks to an optimal bioreactor configuration.

Plant size of 750,000 tonne/year of switchgrass:

- **MESP**= 4.06 $/gal for the base scenario
- **MESP**= 2.92 $/gal for the 2050 H_2 scenario

learning curve effect at the 10-th plant built

Plant size of 750,000 tonne/year of switchgrass:

- **MESP**= 4.06 $/gal for the base scenario
- **MESP**= 2.92 $/gal for the 2050 H_2 scenario

The table shows the **breakdown of costs per gallon of ethanol** for a size of 750,000 tonne/year at the 10-th plant built for the base case scenario. MESP = 3.86 $/gal

Ripartition of the cost per gallon of ethanol	
Switchgrass	6.1 %
Hydrogen	38.7 %
Catalyst	1.2 %
Waste	0.8 %
Utilities	39.4 %
Other Operating Costs	8.0 %
Fixed Costs	0.6 %
Capital Depreciation	1.3 %
Average Income Tax	1.0 %
Average Return on Investment	3.0 %

Discussion & Way Forward

An excellent yield of ethanol per tonne of biomass was obtained. Therefore, less biomass is required to produce the same amount of ethanol, reducing supply issues and transportation costs. Despite the fact that the estimated ethanol selling prices are higher than the present ethanol market price, the results are comparable with those of other technologies for producing ethanol from a lignocellulosic matrix. **A lower MESP could be obtained** thanks to:

- higher concentrations of ethanol in the broth leaving the fermenter;
- using less expensive nutrients for the bacteria;
- changing the reactor configuration of the first CSTR type fermenter as it is energy demanding;
- being more tolerant towards the impurities present in the syngas.

References

[1] eia, Independent Statistics, (2022). https://www.eia.gov/outlooks/ieo/production/sub-topic-01.php.
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[3] KPMG, The hydrogen trajectory, (2020). https://home.kpmg/xx/en/home/insights/2020/11/the-hydrogen-trajectory.html