### Incentives of Micro-alga Dunaliella as Biomass

- Growth ability in medium with high NaCl concentration → mass cultivation
- Extremely tolerant → outdoor cultivation
- High concentration of β-carotene → protection from solar radiation

### Environmental conditions
- Solar radiation: not low
- Temperature: 25 – 35°C
- CO₂ feed
- Nutrients: mostly NaCl

### Products
- Glycerol
- β-carotene
- Proteins
- Extract of fatty acids

### Design of a Micro-algae Biorefinery

#### Single product: Glycerol

#### Adding β-carotene as a product

#### Final flow sheet

### Sustainability analysis

#### Case 1
- Glycerol as final product
- Ethanol/Water = 66/34 w/w
- Nutrients: NaCl, MgSO₄, KH₂PO₄

#### Case 2
- Glycerol and β-carotene as final products
- Ethanol/Water = 95/5 w/w
- Nutrients: NaCl, KNO₃, NH₄H₂PO₄

### Economic Study

#### Table 1

<table>
<thead>
<tr>
<th>Case</th>
<th>Alcohol</th>
<th>Water</th>
<th>Energy</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000</td>
<td>1,000</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>2</td>
<td>950</td>
<td>550</td>
<td>9,500</td>
<td>9,500</td>
</tr>
</tbody>
</table>

### Energy Integration

#### Methodology

- **Targets of energy integration:**
  - Maximum amount of glycerol recovered with purity reaching 100%
  - Decrease in energy consumption regarding the distillation columns
  - Energy cost reduction
  - Ethanol recycling

- Provided that conventional distillation columns are being used, the most common separation methods for a mixture of these components are the direct and indirect methods.
  - Direct separation is considered as the basic configuration for both columns.

#### Degrees of freedom

- The degrees of freedom are the Thermally Coupled Distillation Columns (compensate) and the distillation specifications.
- The configuration: prefractionator, sloppy split and side rectifier is studied to replace the direct simple task and side rectifier is studied to replace the indirect simple task.
- The configurations Sequence 1 and 2 are studied only when the anestropes ethanol/water is present (Scenario B).
- The distillation design specifications are ethanol recovery and ethanol feed.

### Results

#### Scenario A

- The pressure of the columns is set at 2.67 kPa to avoid the azeotrope of ethanol/water.

#### Scenario B

- The pressure of the columns is set at 2.67 kPa to avoid the azeotrope of ethanol/water.

### Scenarios Comparison

- Scenario A provides better results regarding the energy consumption of the distillation columns for both cases.
- The separation is a great challenge due to the small amount of glycerol in the mixture.

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