Biomass conversion into low-cost and sustainable chemicals*

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Biomass

Mixture of highly functionalised chemicals: Structural categories

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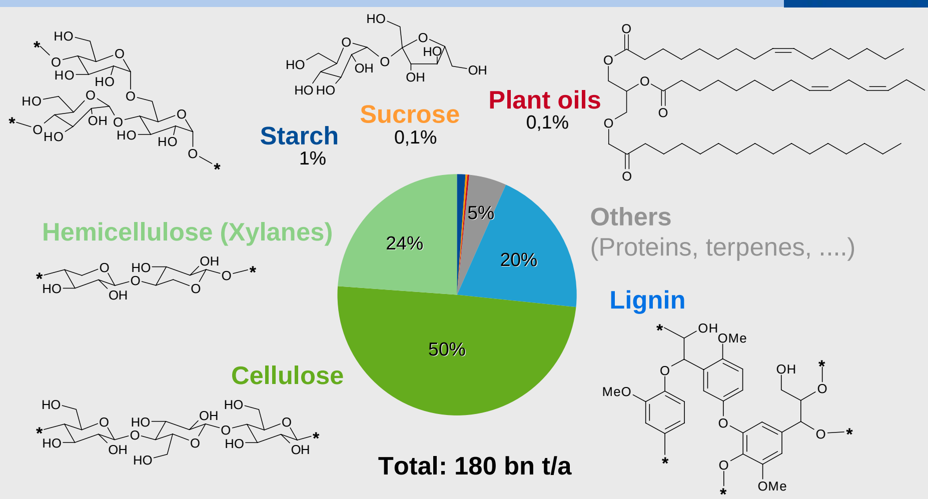

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Key technologies

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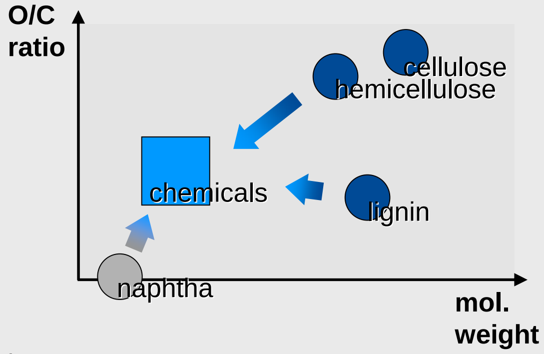
Biomass:
- a mixture of highly functionalised chemicals
- low transport density
- low energy density

Issues:
- solid handling
- fractionation
- dilute solutions
- defunctionalisation



⇒ **Key technologies:**
- refinement
- catalysis (chemical & biotechnological)

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Biorefinery technology

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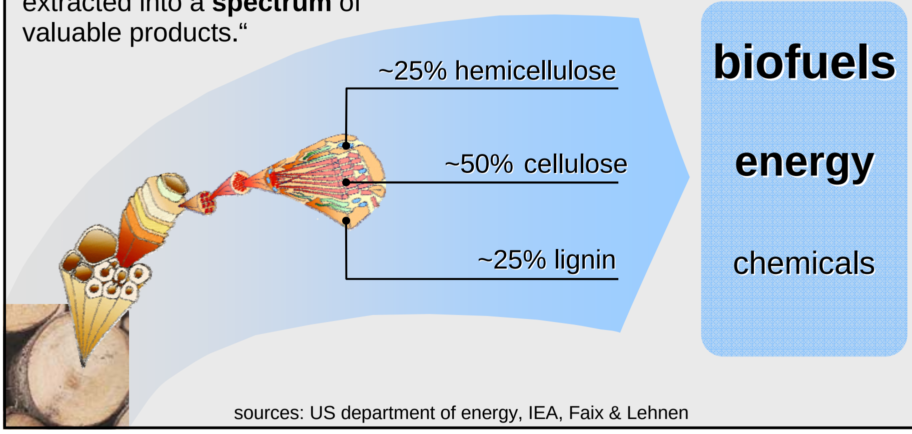
“A biorefinery is an overall concept of a processing plant, where lignocellulosic **biomass** feedstocks are converted and extracted into a **spectrum** of valuable products.“



sources: US department of energy, IEA, Faix & Lehnen

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Biorefinery

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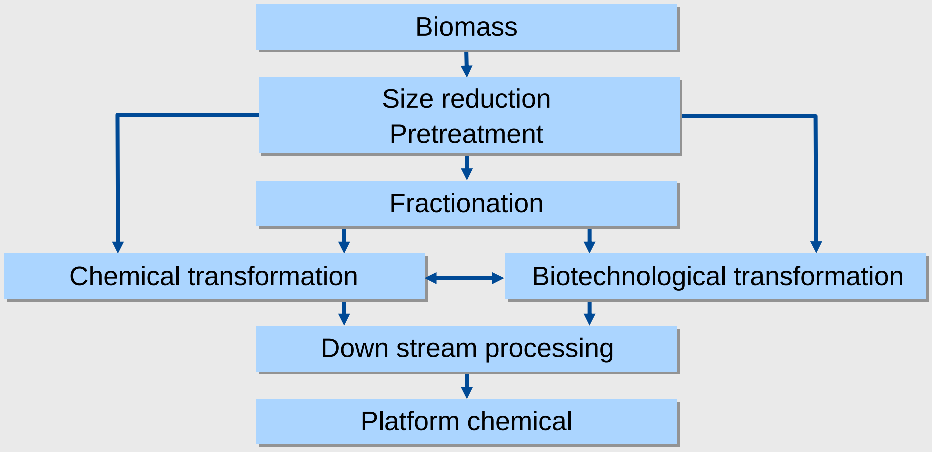

➔ **Efficient refinery technologies are essential**

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Value added chains (1)

Example: grain – based

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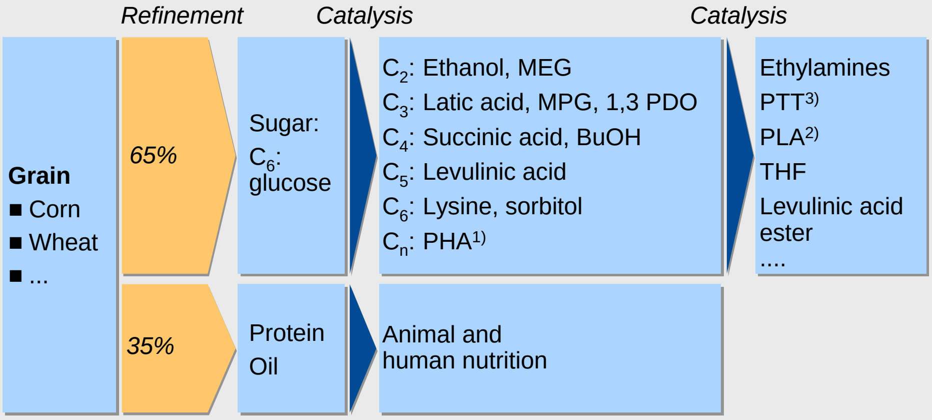

➔ **Catalysis is the key technology**

1) PHA: Polyhydroxyalkanoates
2) PLA: Polylactic acid
3) PTT: Polytrimethylene terephthalate

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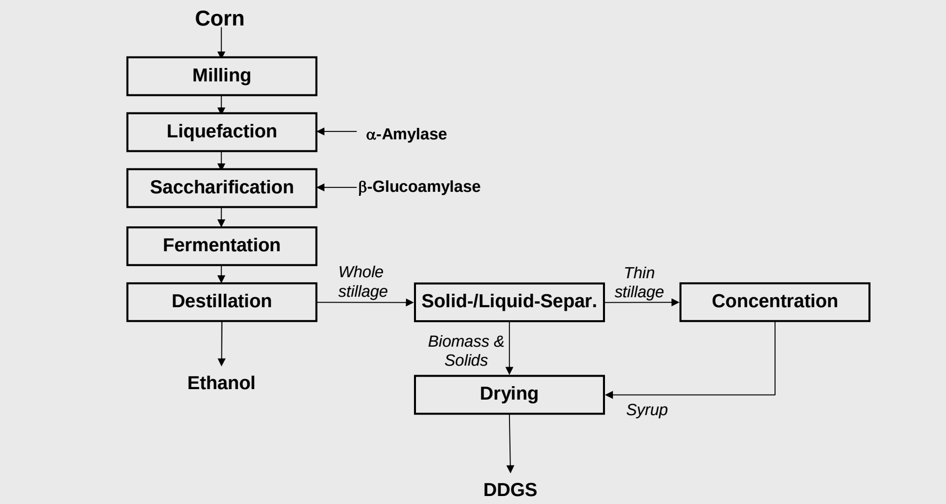
Process idea and overview

Basic flow scheme of bioethanol production



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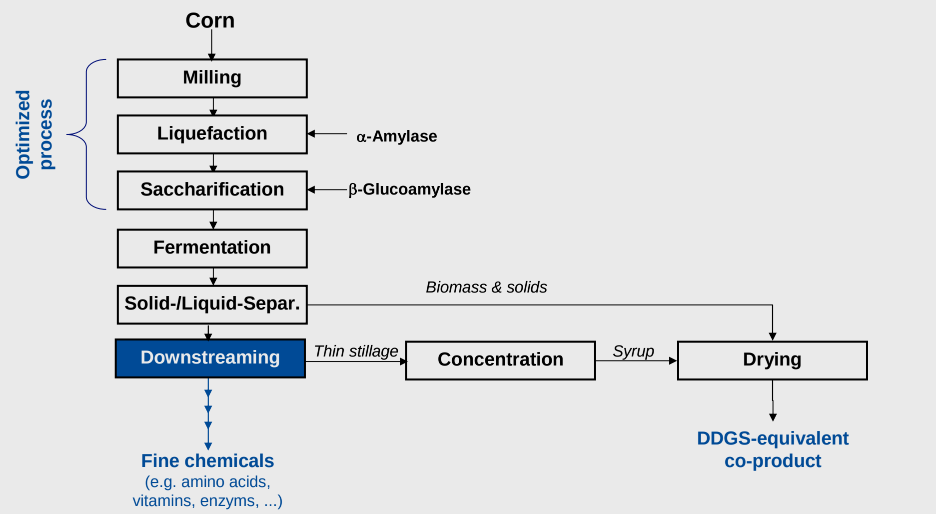
Process idea and overview

Adaption for fine chemical fermentation processes



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Process idea and overview

Pilot-scale development

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Overall view pilot plant

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Fermentation sugar sources

Comparison of existing technologies & BASF process

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Process	Sugar mill	Wet-milling	Dry-milling (BioEtOH)	BASF process
Raw material	Sugar cane	Corn	Corn	Corn
Fermentation sugar purity	> 98 %	> 99% (food-grade)	~ 70%	> 90%
Autonomy of sugar production	Low	Low	High	High
Raw material costs	World market	World market	World market	World market
Investment costs	Low	High[1]	Low	Medium
Production costs	Low	Low[1]	Low	Low

[1] World-scale plants (>1.5 Mio tons/a crushing capacity)

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Value added chains (2)

Example: lignocellulose

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Refinement — *Catalysis* — *Catalysis*

Ligno-cellulose
- Wood
- Straw
- ...

50-80% → Sugar: C_6: glucose; C_5: xylose →
- C_2: Ethanol, MEG
- C_3: Latic acid, MPG, 1,3 PDO
- C_4: Succinic acid, BuOH
- C_5: Furfural, levulinic acid
- C_6: Lysine, sorbitol
- C_n: PHA[1)]

→ Ethylamines, PTT[3)], PLA[2)], THF, Levulinic acid ester, ...

10-30% → Lignin → Energy, Aromatics, ….

➔ **Refinement and catalysis are the key technologies**

1) PHA: Polyhydroxyalkanoates
2) PLA: Polylactic acid
3) PTT: Polytrimethylene terephthalate

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2[nd] generation biorefinery concept

biofuel / chemicals production via fractionation

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biomass → **fractionation** → **monomerisation** → **conversion** → **biobased product**

hemicellulose
cellulose
lignin

why fractionation?

tailor-made conversion conditions for each stream

- space time yield
- capital investment
- flexibility

Source cartoon: Faix & Lehnen

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Example: biomass pretreatment

ionic liquids

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- liquid below 100 °C
- non flammable
- immiscible with many organic solvents
- BASF know-how & production
- various emerging applications
- dissolution of (ligno-)cellulose
- exclusive license from the University of Alabama (patents of Prof. Rogers)

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Example: biomass pretreatment

biorefinery with ionic liquids

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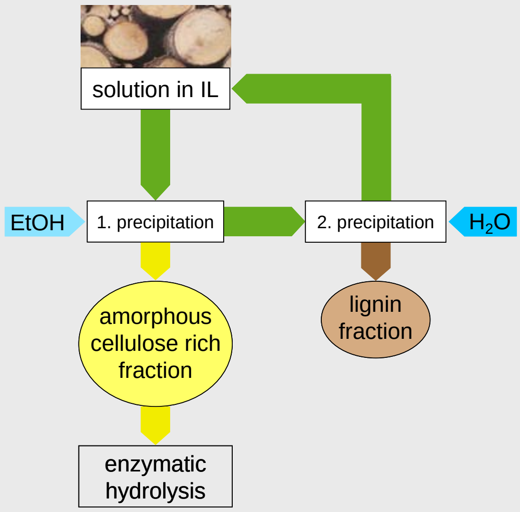

- screening of >50 ILs
- screening of parameters:
  - temperature
  - precipitating agent
  - water content of the IL
  - precipitation protocol
- series of experiments in closed process cycles
- two patents filed:
  WO 2008090155
  WO 2008090156

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Example: biomass pretreatment

digestion of switchgrass by cellulases

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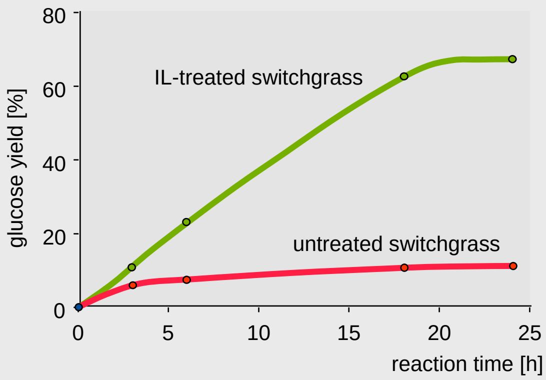

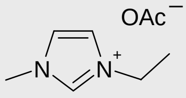

EMIM OAc

- disintegration of the lignocellulose structure (hydrolysis rate x7)
- challenges:
  - \>99% IL-recycling
  - high investment costs
  - energy costs

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Requirements for a raw material change

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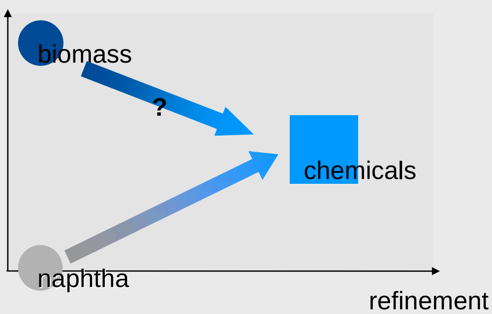

- favourable price ratio of renewable versus fossile feedstocks
- integration into existing value added chains (BASF „Verbund“)
- feedstock change without product change
- competitiveness (economy of scale)
- sustainability (BASF eco efficiency analysis)

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Chemicals *via* Fermentation

Succinate as Intermediate and Monomer

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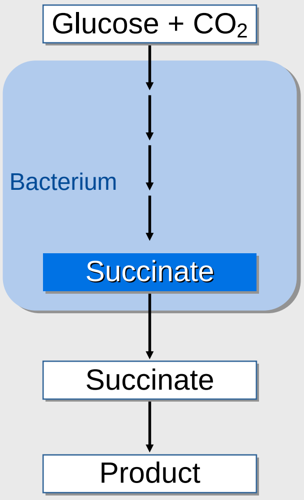
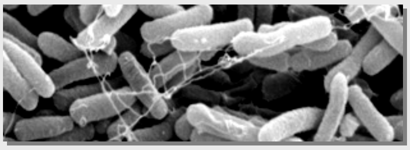


Chances:

- Succinate as monomer and intermediate
- Potential for 100% yield
- CO_2 fixation

Challenges:

- Identify suitable production organism
- Improve microbial strain & fermentation
- Develop *"In broth chemistry"*



Succinate producing bacterium

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Chemicals *via* Fermentation

Succinate as Intermediate and Monomer

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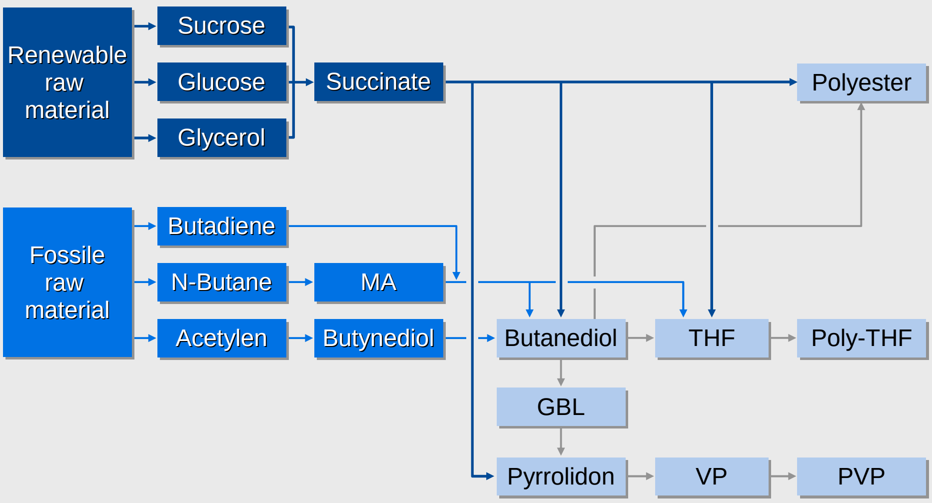

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Chemicals *via* Fermentation

Diaminopentane –
New Monomer by Synthetic Metabolic Pathways

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Glucose
Bacterium
Lysine
Lysine

Glucose
Bacterium
Lysine
1.5-Diaminopentane
1.5-Diaminopentane

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Example: glycerol conversion

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glycerol

- epichlorohydrine
- propylene glycol
- acrylic acid
- glycerol carbonate
- glycerol oligomers

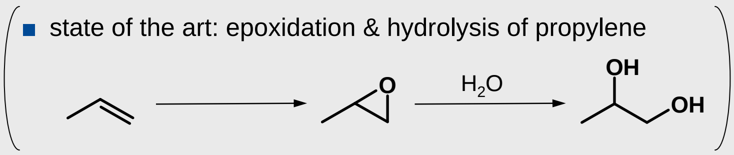
technical process | pilot plant | lab scale

Example: propylene glycol
alternative process based on glycerol

- hydrogenation of glycerol

- challenges
  - volatile & rising glycerol price
  - reliable sourcing of >100.000 t/a difficult

- state of the art: epoxidation & hydrolysis of propylene



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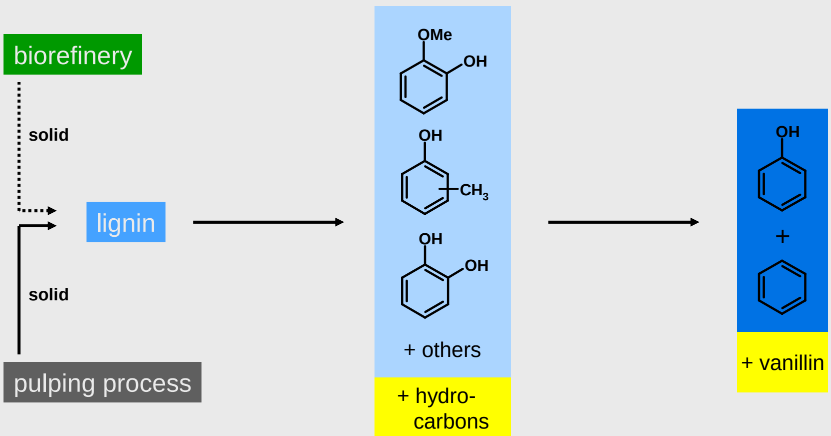
Example: aromatics from lignin



- biomass: 20 - 30% lignin
- max. yield of phenol / benzene = 45% from lignin

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Summary
Chemicals from renewable raw materials

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- Renewable raw materials are well-established in the chemical industry
- Sufficient renewable raw materials must be available at competitive prices:
  - ➔ A rising price ratio of 'fossil to renewable raw materials' elevates the importance of renewable raw materials
  - ➔ An increasing raw material competition between chemical products based on renewable raw materials, biofuels and nutrition may be expected
- Cost effectiveness and technical feasibility of base chemicals from renewable raw materials have to be explored
- Sustainability has to be analyzed carefully for every alternative process or product (life cycle analysis, e.g. via BASF eco-efficiency analysis)
- Chemical products from renewable raw materials requires:
  - ➔ Verbund structure and value added chains based on renewable raw materials
  - ➔ A broad technology portfolio:
    - chemical catalysis: higher selectivity and stability
    - biotechnological catalysis: higher stability and space time yield
    - chemical engineering: solid handling and downstream

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Potato Leaf Amflora