# Building sustainable biomass-to-biofuel systems:

## Prospects for biohydrogen generation in two EU regions

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HYvolution

# Outline

- Overview of EU HYVOLUTION Project
- Exploring the regional dimension of feasibility and sustainability of the biomass-to-biohydrogen generation chains
- Mapping the overall biohydrogen generation potential in 2 typical EU regions
- Selection of most promising feedstocks and their potential availability in the regions
- Prospects in a 20 year perspective for the regions
- Crucial stakeholders and policy aspects

# IP "HYVOLUTION" Project
# Non-Thermal Production of Pure Hydrogen from Biomass

**ACKNOWLEDGMENTS**

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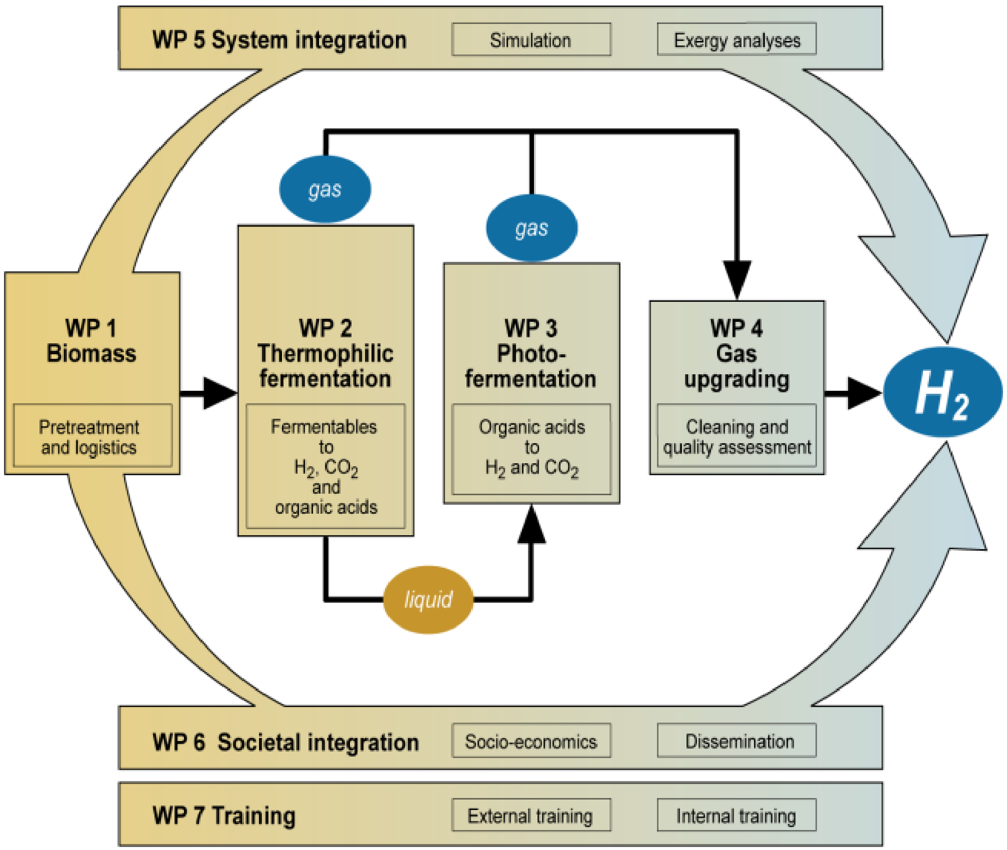
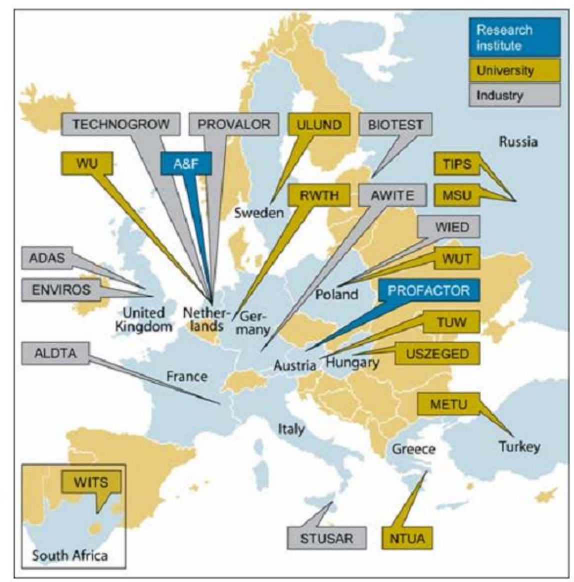



**22 partners from 13 countries**
**Project duration: 2006-2010**



# The main objectives of Hyvolution project:

- the development and optimization of a 2-stage bioprocess for the generation of pure hydrogen from biomass ,
- the simultaneous optimization of technical, economic, environmental and social parameters of the whole biomasss-to-biohydrogen chain, and
- the exploration of the sustainable operation of the specific technology under various regional conditions within EU, and

# IP "HYVOLUTION"
## Non-Thermal Production of Pure Hydrogen from Biomass

$C_6H_{12}O_6 + 6\ H_2O \rightarrow 6\ CO_2 + 12\ H_2$ $\Delta G_o' = +3\ kJ$

$C_6H_{12}O_6$ → Water soluble monomeric and oligomeric carbohydrates

$C_6H_{12}O_6 + 2H_2O \longrightarrow 2CO_2 + 2CH_3COOH + 4H_2$ $\Delta G_o' = -206\ kJ$

*(hyper)thermophilic bacteria*

photons

$CH_3COOH + 2H_2O \longrightarrow 2CO_2 + 4H_2$ $\Delta G_o' = +104\ kJ$

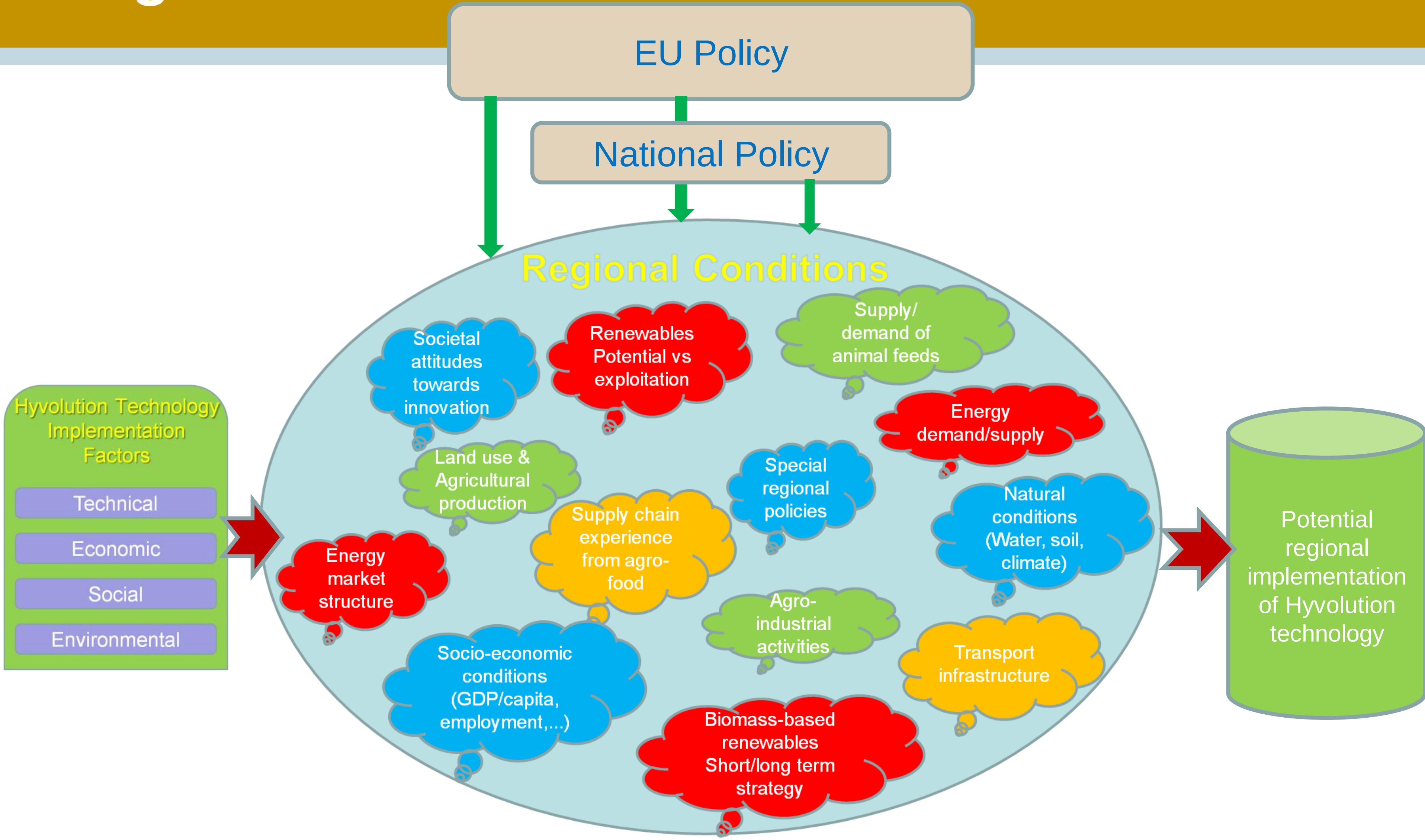
*photosynthetic bacteria*

Major advantage: Potential for feasible and sustainable operation of relatively small units, up to 2MW (fed by 8000 dry tons of biomass/a)

### Feedstocks for Hyvolution technology

- The carbohydrate resources from agricultural and agro-industrial sector are considered as potential feedstocks for the examined technology. (Claassen et al, 1999)
- The overall annual hydrogen generation potential, based on the major, non forest originated, EU biomass resources, has been assessed as about 30 Mt (Karaoglanoglou et al, 2008).

# Regional dimension




Data categories for the definition of the regional system

| | |
|---|---|
| Biosystem | Energy |
| Supply chain | Socio-economics |

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# Regional dimension

**2 basic selection criteria:**

**GDP/capita and Innovation index, both have a direct impact on the economic and social structure of the regions**

**Target: to derive useful insight through two “extreme” EU cases**

«Industrial North»

| | | |
|---|---|---|
| **Innovation Score** | | |
| Thessaly | 0,1 | (200/203 Regions) |
| Zuid Holland | 0,58 | (38/203 Regions) |
| Range of Scores | 0,01-0,90 | |
| **GDP/Capita** | | |
| Thessaly | 73,8 | |
| Zuid Holland | 134,5 | |
| EU Average | 100 | |
| Range of GDP/capita within EU | 24-303 | |

«Rural South»

# Regional dimension

| | "Rural South": THESSALY | "Industrial North": ROTTERDAM |
|---|---|---|
| Land use / Main Agricultural Products | - Total Agricultural Land: 490000 ha<br>- Cotton: 150000 ha<br>- Wheat: 110000 ha<br>- Barley: 14000 ha<br>- Sugar beet: 7000 ha<br>- Fallow/pasture land/other not utilised agricultural land: 38000 ha | - Total Agricultural Land: 150000 ha<br>- Cereals: 12500<br>- Potatoes: 9000 ha<br>- Sugar beet: 4000 ha |
| Estimated Agricultural Income | 850-2500 €/ha (40-50% coming from national or EU subsidies) | 900-2500 €//ha (much higher for greenhouse agriculture) |
| Agro-industrial Units | 2 large wheat mill units<br>1 large juice production unit<br>Several small canned product units<br>Several oil production/processing units | - oilseed crushing<br>- grain processing<br>- large beer breweries<br>- potato processing facilities |
| Spatial Distribution of Agro-industrial Units | - 2 wheat mills are placed in Larissa and Magnesia prefectures<br>- The juice production unit is placed in Magnesia prefecture<br>- The rest units are distributed throughout the 4 prefectures | Main agro-industrial units are placed around the port of Rotterdam, within a 30 km radius |
| Potentially Available Agricultural and Agro-industrial By-products | - wheat bran<br>- wheat and barley straw<br>- pulp from juice industry<br>- cake from oil industry | - wheat bran<br>- potato steam peels<br>- cake from oil industry |
| Transport Infrastructure | - a major port in Magnesia prefecture<br>- good road network | - Rotterdam port (Europe's cheapest bunker port): the third largest port in the world<br>- railway and road network supplying the port |
| Available Supply Chain Infrastructures | Already existing import (oil/oil seeds, cereals) and export (flour and other processed cereal and juice products) activities in the region | The agro-industrial units of the region are largely based on imported feedstock. The Agri-bulk handled in Rotterdam is about 9.5 million tones |
| Renewable Energy in the Region | 135 MW power produced in H/E plants, and 2 biodiesel production units | - electricity production using imported wood residues(1 Mton dry wood residues)<br>- wind energy |
| Biomass-based Energy Production | - 2 biodiesel production units (using imported feedstock) of 55000 tonnes total capacity<br>- 1 bioethanol unit (from sugar beet and cereals) to be operational within 2010 * | - co-firing of wood for electricity<br>- surplus of heat from oil refinery<br>- farm scale biogas digesters<br>- several bioethanol facilities around the port area |
| Population | About 750000 persons | About 1600000 persons |
| GDP/Capita - Employment | 73.2 (considering 100 the GDP of EU25)<br>13% employed in primary sector | - 204 billion Euro regional product<br>- 21% of the total employment of NL, 1.5% in primary |
| Special Regional Conditions - Policies | Governmental initiatives encouraging the land use change (especially from cotton to alternative crops) | Sustainable production program for all the economic sectors |
| Social Acceptance of Bioenergy Projects | "Thessaly Biofuel Technology Platform" along with the Thessaly University play a positive role in the social acceptance of biofuels | - Positive public response to "green electricity"<br>- Negative public response to large biofuel plant projects |

# "Mapping the Landscape" of potential

## Potential Feedstocks for Hydrogen Production

| CROPS, CROP PARTS AND AGRO-INDUSTRIAL RESIDUES AS POTENTIAL FEEDSTOCKS | | | | by-products | | | |
|---|---|---|---|---|---|---|---|
| | **Crop Category** | **Crop** | **main product** | **leafy biomass** | **stems-stalks** | **pulps-cakes** | **sludges-other wet residues** |
| Crops already cultivated for nutritional needs | Sugar Crops | **sugar beet** | sugar | leaves | - | pulp | molasses / sludge |
| | Starch Crops | **potato** | tuber | leaves | - | peels | starch |
| | | **wheat** | grain | - | straw | husks,hulls,bran | wet milling wastes |
| | | **barley** | grain | - | straw | husks,hulls,bran | wet milling wastes / brewery waste |
| | | **maize** | grain | - | straw / cob | corn-oil cake | wet milling wastes |
| | | **other cerials** | grain | - | straw | husks,hulls,bran | wet milling wastes |
| | | **rice** | grain | - | straw | husks,hulls,bran | wet milling wastes |
| | Other Food Crops | **grapes** | wine, juice | - | vine | pulp | wet residue |
| | | **apples** | canned prod., juice | - | wood, trimmings | pulp | wet residue |
| | | **other fruits** | canned prod., juice | - | wood, trimmings | pulp | wet residue |
| | | **vegetables** | canned prod. / juice | leaves | - | - / pulp | wet residue |
| | | **oil seeds** | veg. oil | - | straw | oil cake | wet residue |
| Energy crops | Sugar Crops | **sw. sorghum** | sugar | leaves | bagasse | - | sludge |
| | Lignocellulosic crops | **Miscanthus** | stems/stalks | leaves | - | pulp | - |

**15 crop main product and 29 farm or industrial level by-products and residues were considered as potential feedstocks**

# “Mapping the Landscape” of potential for THESSALY

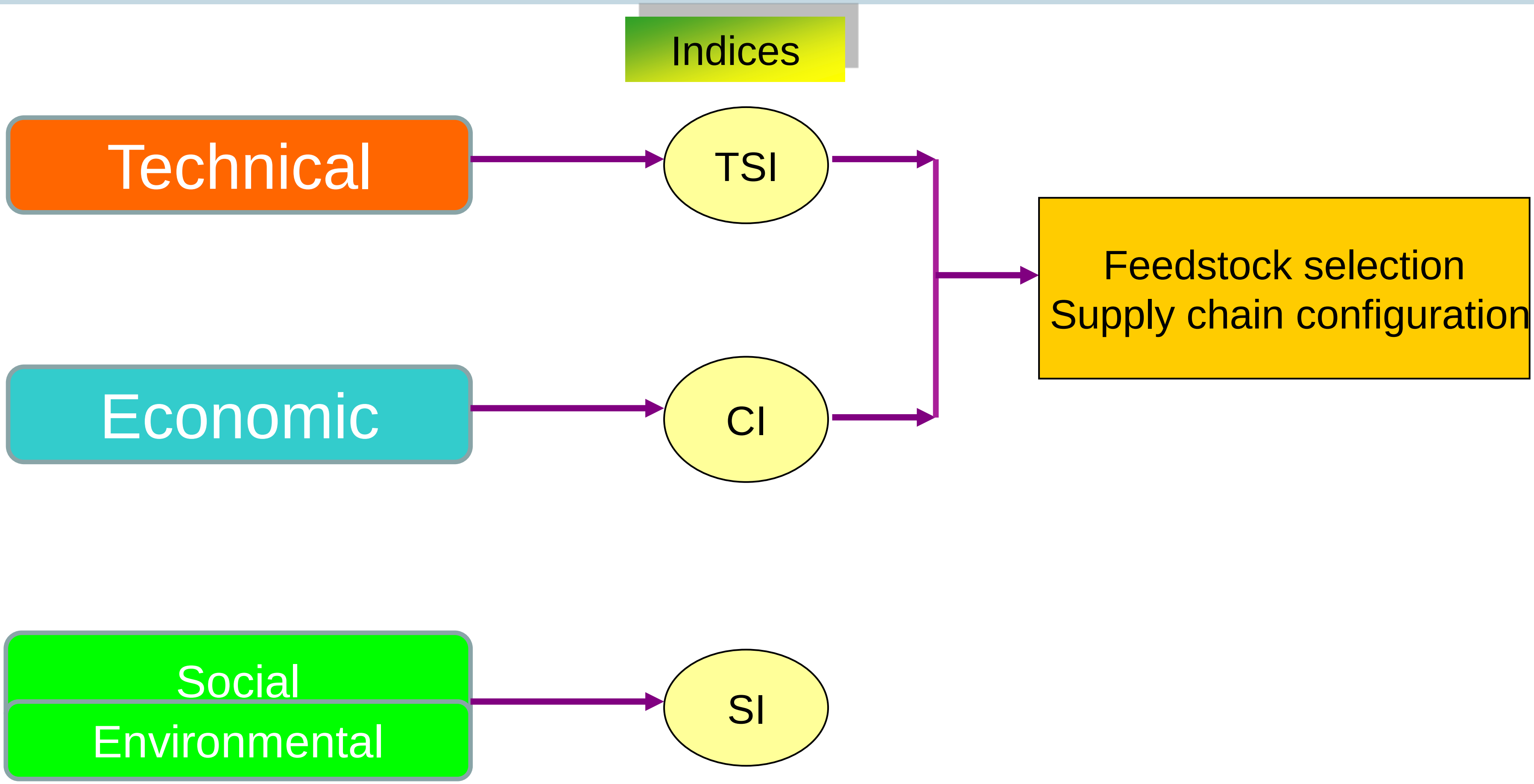
**HYDROGEN POTENTIAL (10^3 t) FOR THESSALY**

| | Crop Category | Crop | 10% of the main product production as feedstock for hydrogen* | by-products: leafy biomass | by-products: stems-stalks | by-products: pulps-cakes | by-products: sludges-other wet residues | Total Hydrogen Production Potential |
|---|---|---|---|---|---|---|---|---|
| Crops already cultivated for nutritional needs | Sugar Crops | sugar beet | 0,356 | 1,433 | - | 0,996 | 0,897<br>0,089 | 3,771 |
| | Starch Crops | potato | 0,022 | 0,000 | - | 0,031 | 0,015 | 0,068 |
| | | wheat | 1,326 | - | 11,236 | 1,326 | 0,474 | 14,363 |
| | | barley | 0,178 | - | 1,505 | 0,178 | 0,063<br>- | 1,923 |
| | | maize | 0,979 | - | 11,746<br>4,894 | 0,979 | 0,350 | 18,947 |
| | | other cereals | - | - | - | - | - | |
| | | rice | 0,002 | - | 0,016 | 0,002 | 0,001 | 0,021 |
| | Other Food Crops | grapes | 0,028 | - | 0,826 | 0,445 | 0,065 | 1,363 |
| | | apples | - | - | - | - | - | 0,000 |
| | | other fruits | 0,013 | - | 3,927 | 0,143 | 0,022 | 4,106 |
| | | vegetables | 1,169<br>0,000 | 1,451 | -<br>- | 0,164<br>0,000 | 0,029<br>0,000 | 2,814 |
| | | oil seeds | - | - | 5,835 | 4,237 | 0,076 | 10,147 |
| Energy crops | Sugar Crops | sw. sorghum | 15,223 | 2,664 | 4,262 | - | 0,381 | 22,530 |
| | lignocellulosic crops | miscanthus | - | - | - | - | - | - |
| | | Total Hydrogen production Potential | 19,297 | 5,548 | 48,509 | 8,501 | 2,461 | 80,054 |

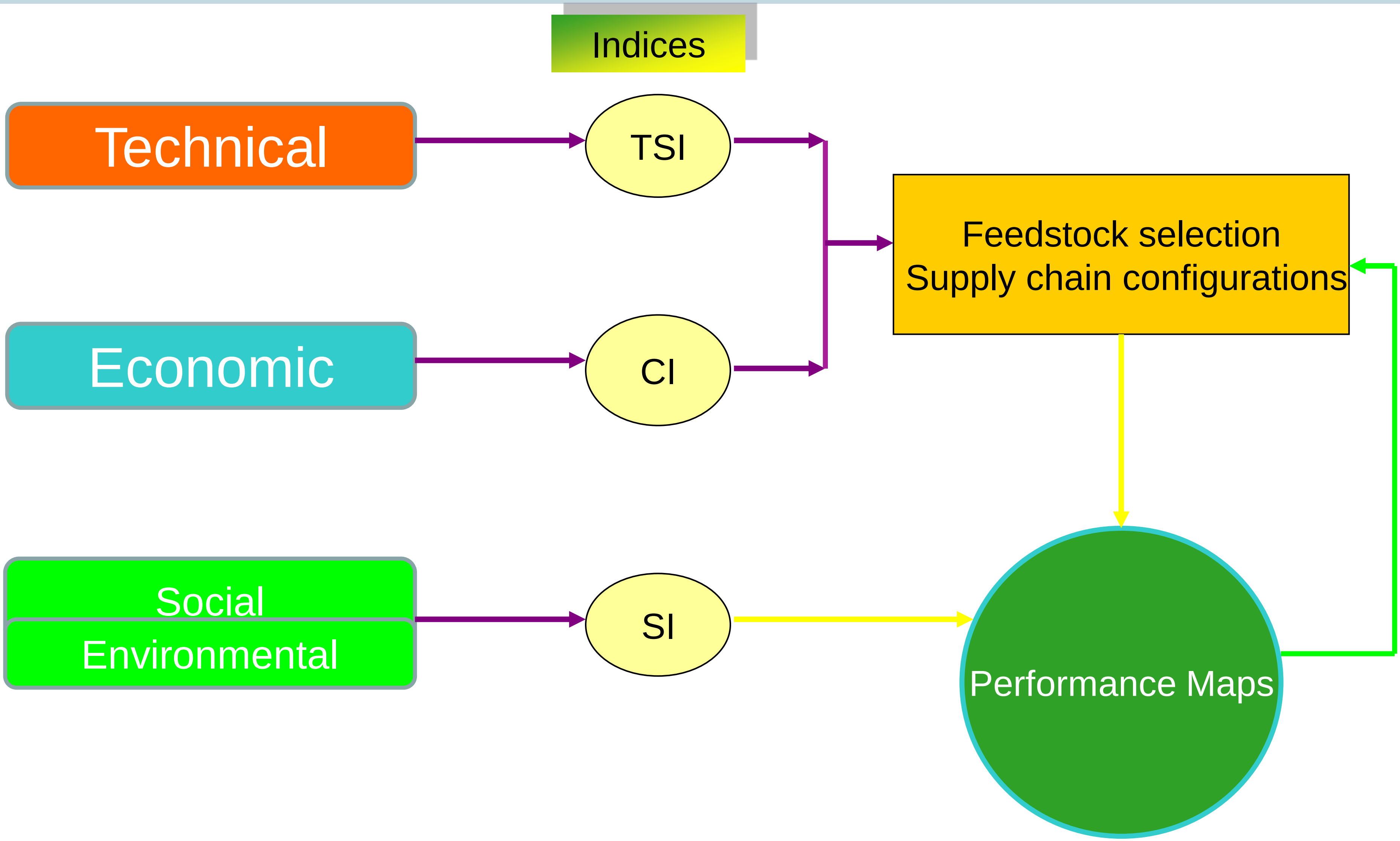
| | |
|---|---|
| <1.00 | (red) |
| 1.00-10.00 | (light orange) |
| 10.00-20.00 | (green) |

* 100% of main product for H2 production in the case of energy crops

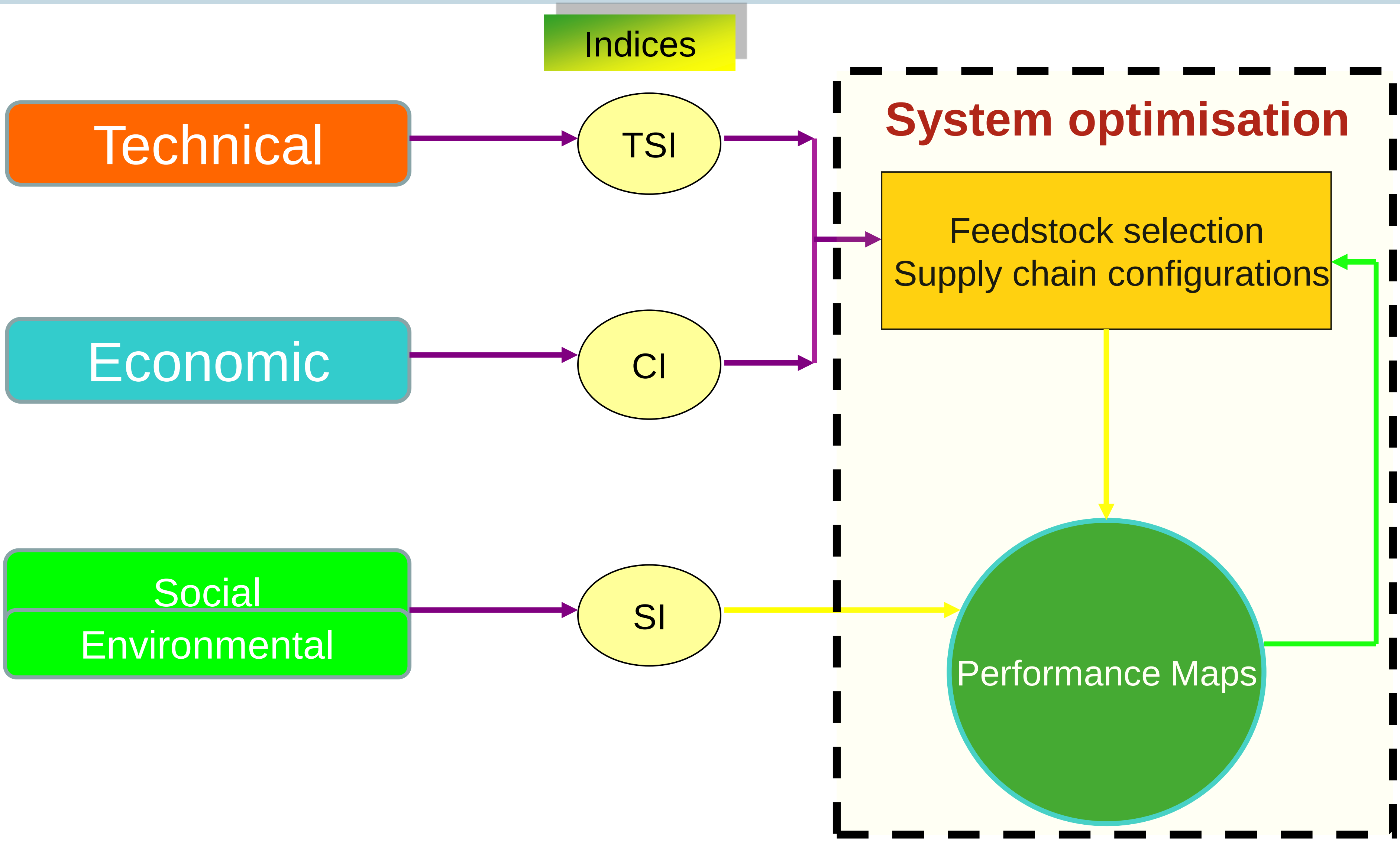
# Selection of promising feedstocks and chains



# Selection of promising feedstocks and chains



# Selection of promising feedstocks and chains



# Promising feedstocks

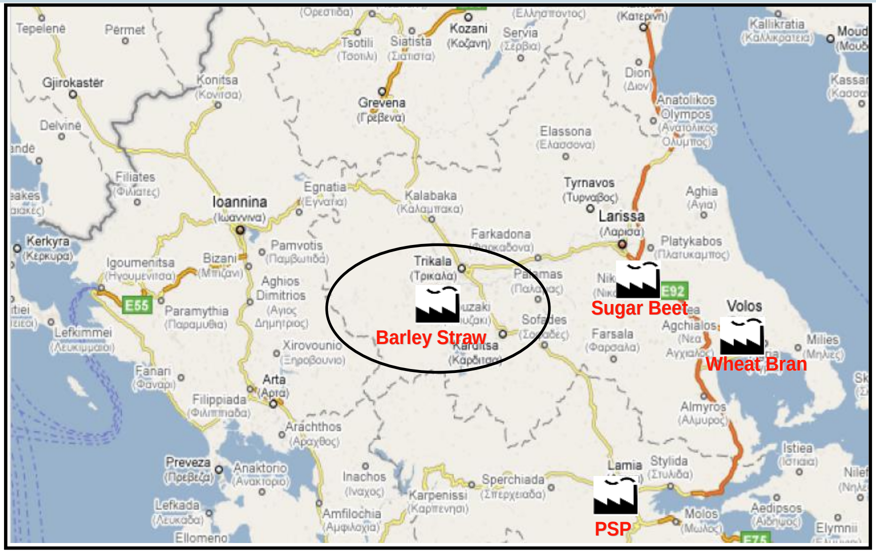
## Selected Feedstocks: Techno-Economic Criteria

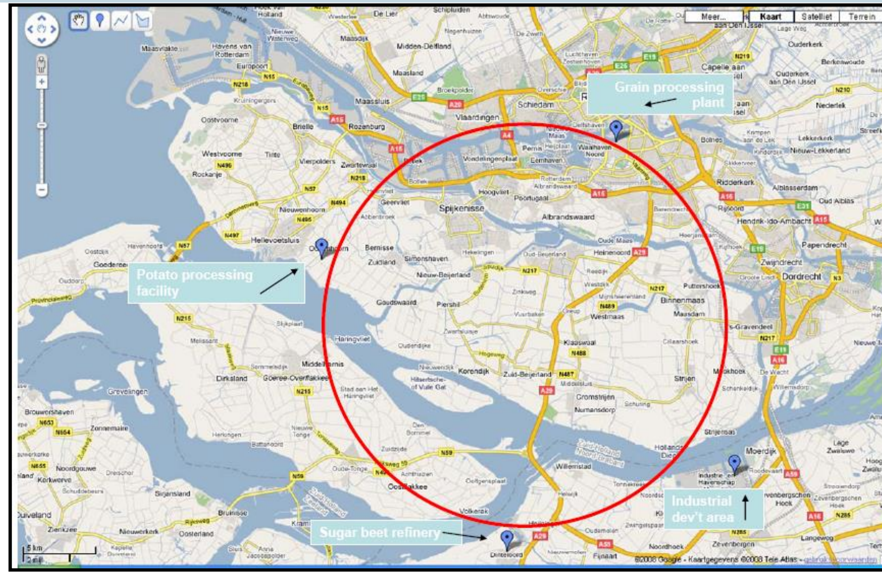
Feedstocks selected by applying, in a top down approach, the Methodology developed in Hyvolution for the Assessment of Technical and Economic Feasibility of Biomass sources:

| |
|---|
| ***Sugar beet*** |
| ***Potato steam peels (PSP)*** |
| ***Wheat bran*** |
| ***Barley straw*** |

| | |
|---|---|
| Biohydrogen generation potential from 4 selected feedstocks in Thessaly | 3.2 kt |

# Assessing the current perspectives in the two regions




| Potential Feedstock | Location | Co-operation with existing or potential industrial units | Hydrogen Unit Type | Potential Capacity |
|---|---|---|---|---|
| **Sugar beet** | Larissa | Bio-ethanol Production Unit (under construction) | Add-on | >> 8000 dry t/year |
| **Wheat Bran** | Volos | Wheat Mill (locally produced and imported wheat) | Add-on | > 8000 dry t /year |
| **Potato Steam Peels** | Lamia (city close to Thessaly region) | Potato Chips Production Plant | Add-on | ~ 8000 dry t/year |
| **Barley Straw** | Karditsa-Trikala | Regionally produced straw | Local stand alone | ~ 8000 dry t/year |

| Potential Feedstock | Location | Co-operation with existing or potential industrial units | Hydrogen Unit Type | Potential Capacity |
|---|---|---|---|---|
| **Sugar beet** | Rotterdam port area | Sugar Production Unit | Add-on | >> 8000 dry t/year |
| **Potato Steam Peels** | Rotterdam port area | Potato Chips Production Plant | Add-on | >> 8000 dry t/year |
| **Wheat Bran** | Moerdijk industrial area | Wheat Mill (mainly imported wheat) | Add-on | >> 8000 dry t /year |
| **Barley Straw** | Rotterdam agricultural land area | Regionally produced straw | Local stand alone | ~ 8000 dry t/year |

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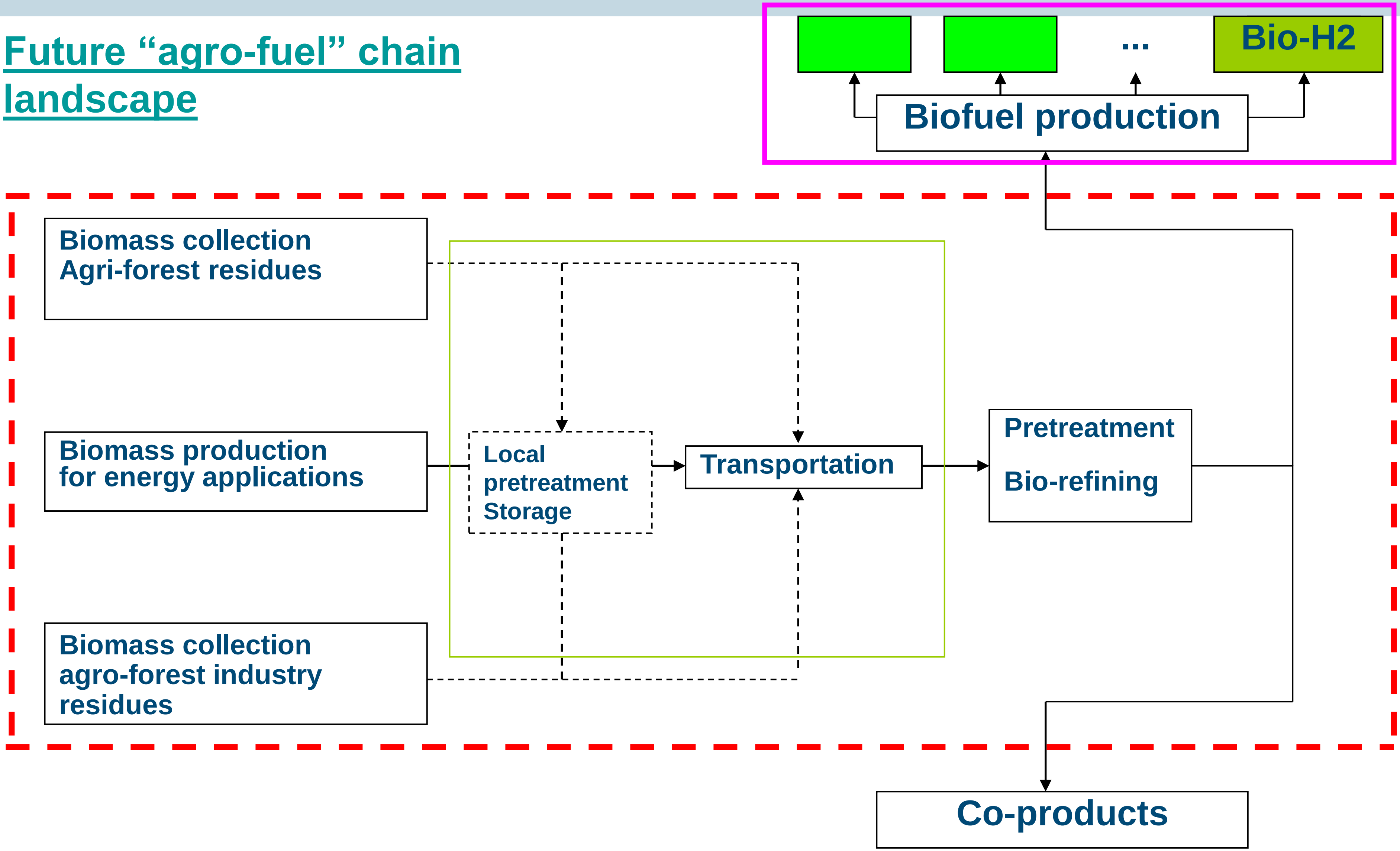
# Future trends and long range dynamics

## Future "agro-fuel" chain landscape



# Future trends and long range dynamics

## Alternative Biomass-to-Hydrogen Pathways

| | |
|---|---|
| **High Carb – Low DM:**<br><br>Biomass -> BioH2<br>(*HYVOLUTION*) | **High Carb – High DM:**<br><br>Biomass -> Bioethanol -> Reforming -> H2 |
| **Low Carb – Low DM:**<br><br>Biomass -> Biogas<br>-> Reforming -> H2 | **Low Carb – High DM:**<br><br>Biomass -> Thermo-chemical Gasification -> H2 |

# Prospects in a 20 year perspective

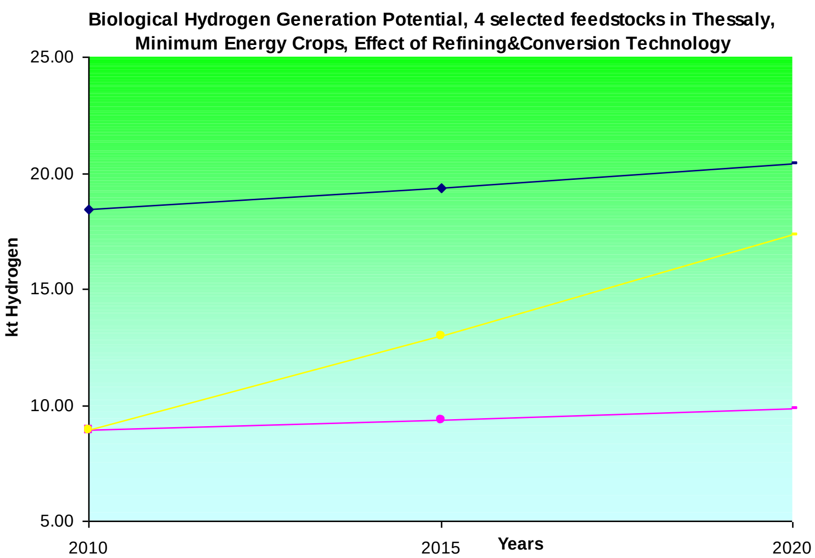
Assessing the future hydrogen demand
Thessaly (2010-2030)

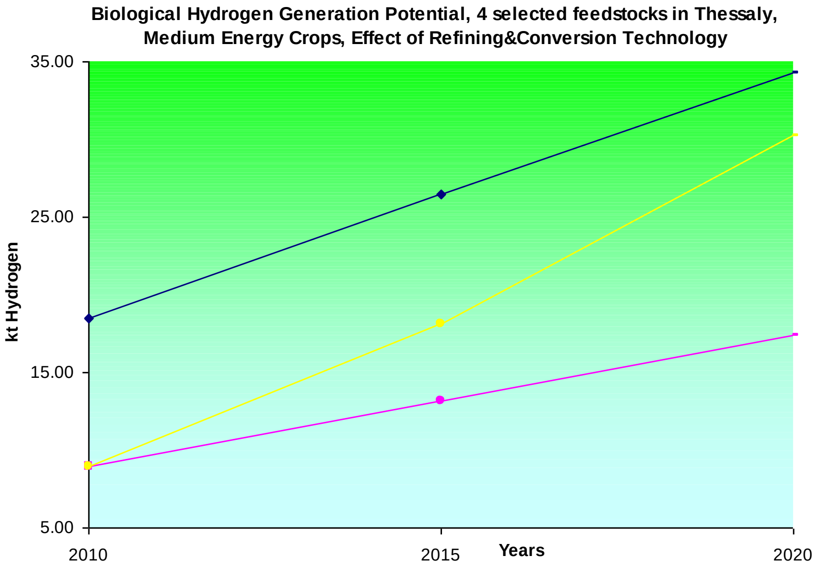
2010 – 2020: 1.5 TWh/year H2 production- consumption in Greece
10% in Thessaly and Ipirus
8% of H2 production from Biomass → 43.2 TJoule/year

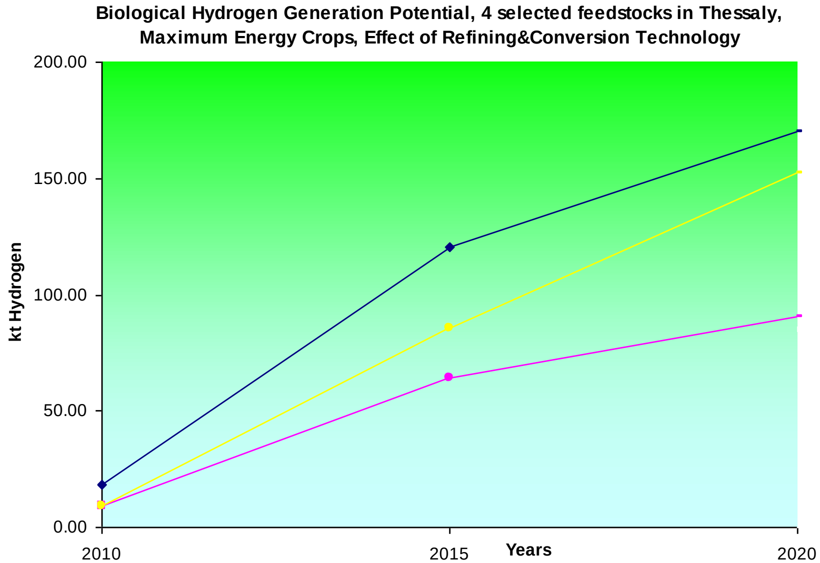
2020 - 2030: 9.5 TWh/year H2 production- consumption in Greece
10% in Thessaly and Ipirus
20% of H2 production from Biomass → 720 TJoule/year

Based on EU Project HyWays

# Future prospects in Thessaly



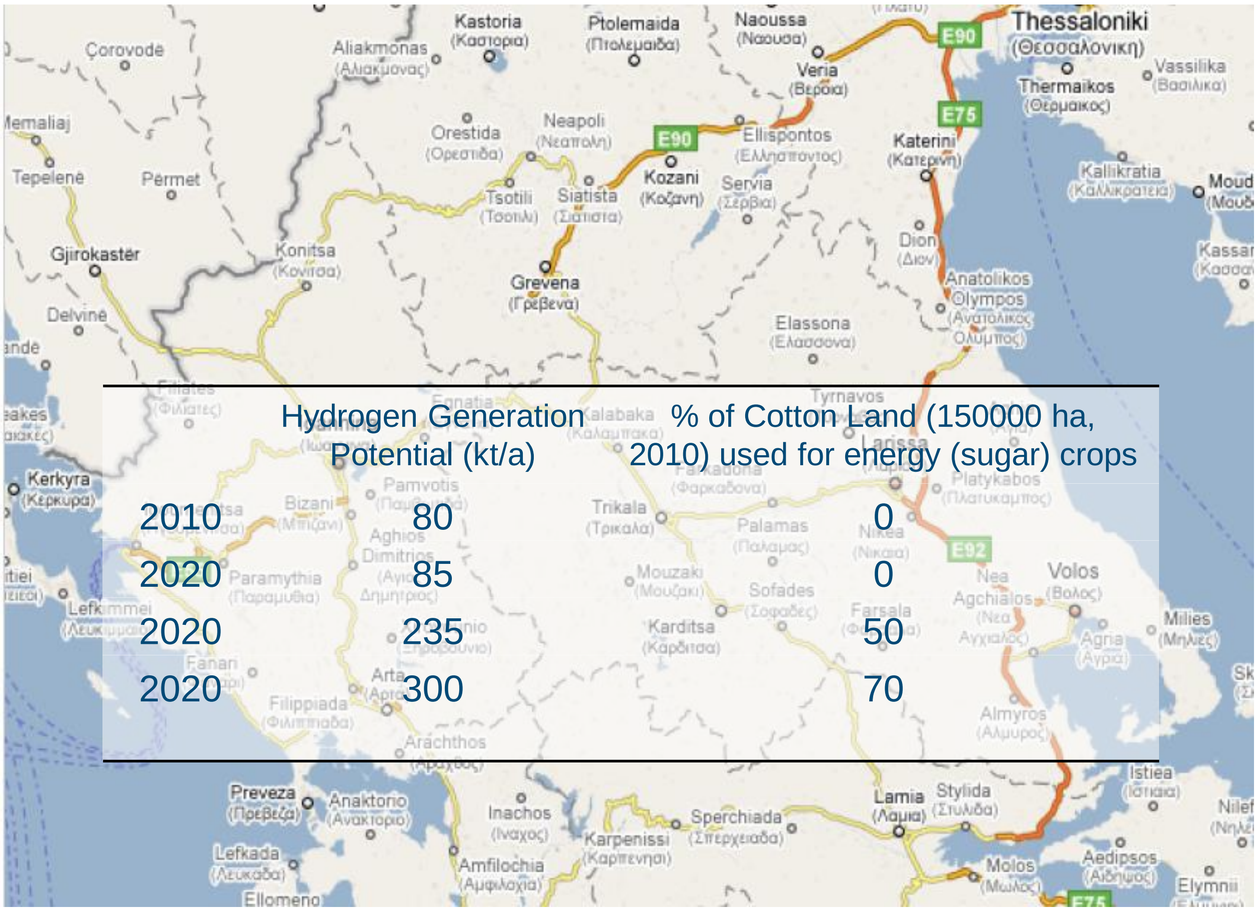




Supply-side scenarios for 4 selected feedstocks based on land use change and technological efficiency improvement in pretreatment and conversion processes

- Maximum potential
- Current refining and conversion technology
- Gradual improvement up to an optimum of refining &conversion

# Future prospects in Thessaly

## Total biohydrogen generation potential based on land use scenarios

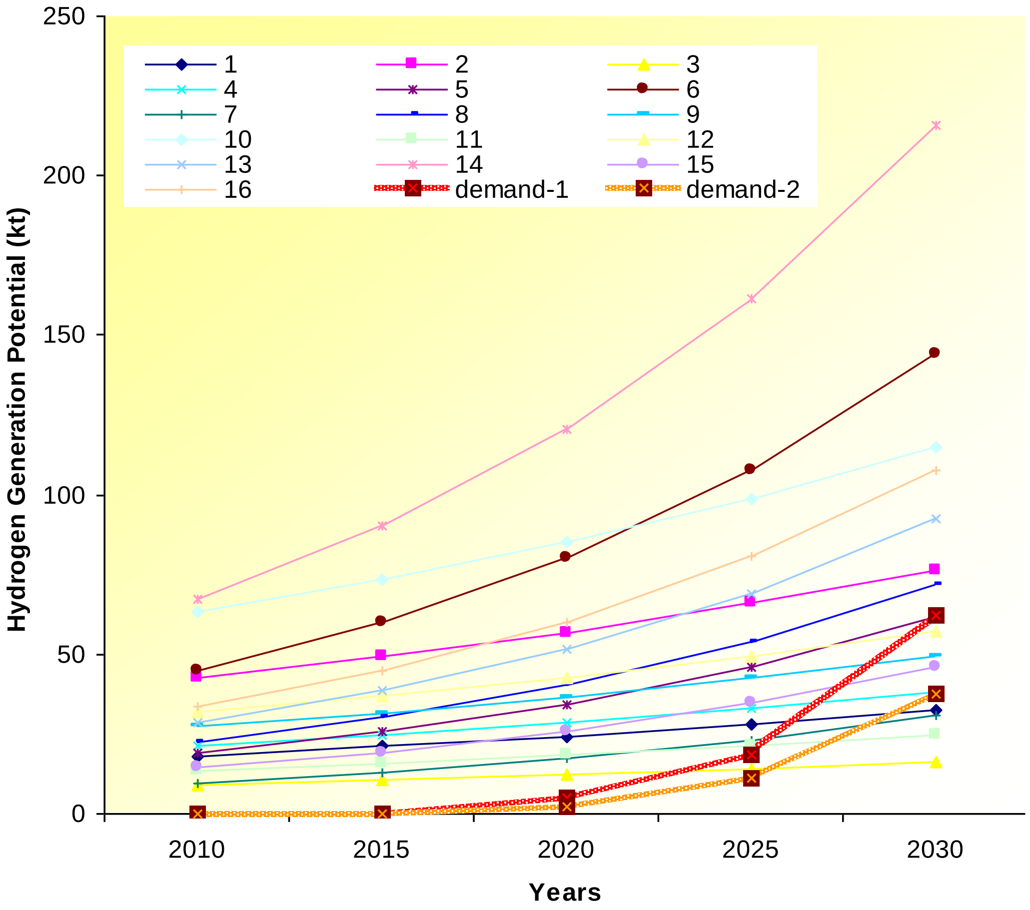



| | Hydrogen Generation Potential (kt/a) | % of Cotton Land (150000 ha, 2010) used for energy (sugar) crops |
|---|---|---|
| 2010 | 80 | 0 |
| 2020 | 85 | 0 |
| 2020 | 235 | 50 |
| 2020 | 300 | 70 |

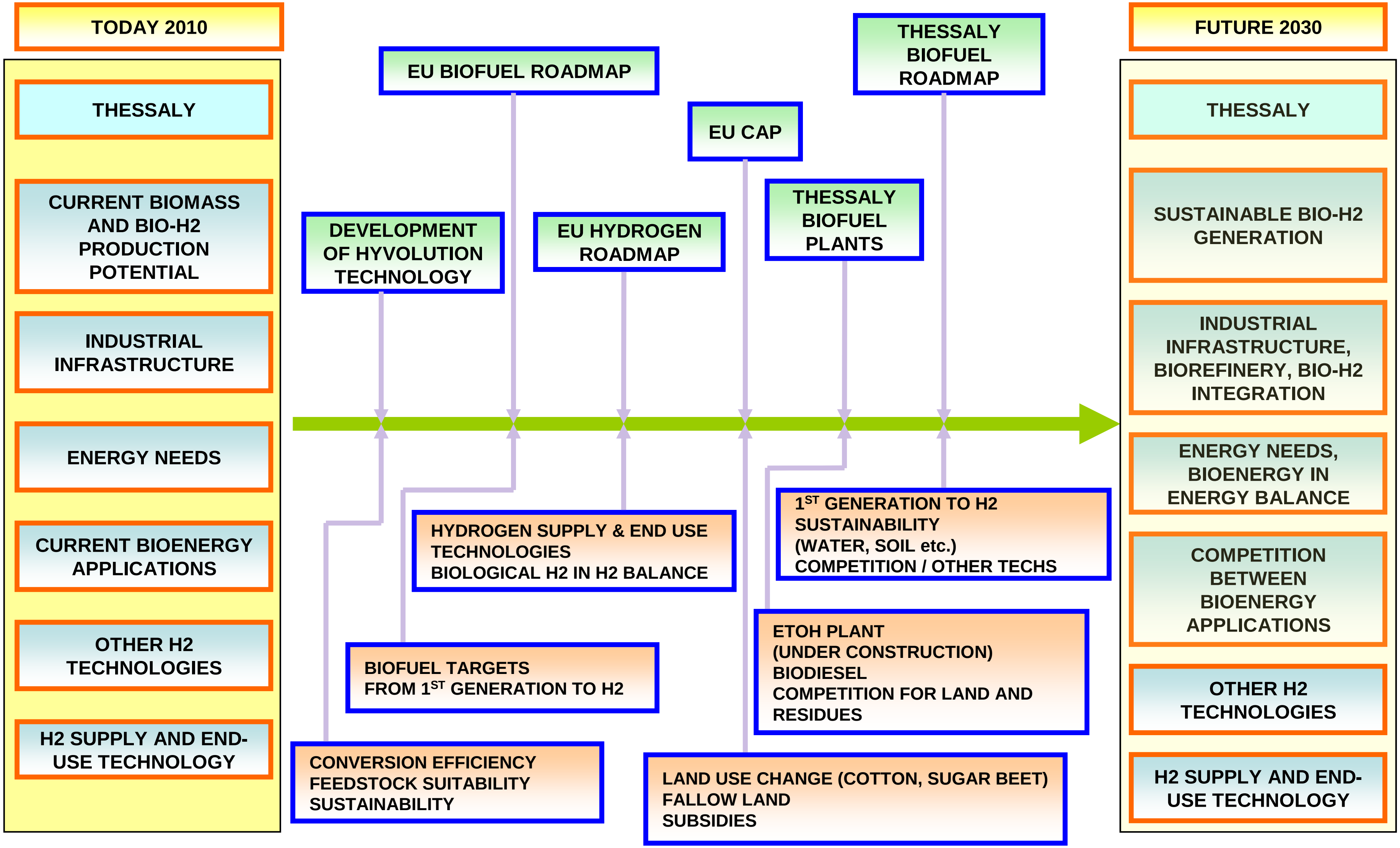
# Future prospects in Rotterdam

| Scenarios | Annual increase in agribulk handled in industries of port area | Available by-products/residues for hyvolution | Carbohydrate recovery | Hydrogen conversion * |
|---|---|---|---|---|
| 1 | 3% | 10% | 30% | 100% |
| 2 | 3% | 10% | 70% | 100% |
| 3 | 3% | 10% | 30% | 50% |
| 4 | 3% | 10% | 70% | 50% |
| 5 | 6% | 10% | 30% | 100% |
| 6 | 6% | 10% | 70% | 100% |
| 7 | 6% | 10% | 30% | 50% |
| 8 | 6% | 10% | 70% | 50% |
| 9 | 3% | 15% | 30% | 100% |
| 10 | 3% | 15% | 70% | 100% |
| 11 | 3% | 15% | 30% | 50% |
| 12 | 3% | 15% | 70% | 50% |
| 13 | 6% | 15% | 30% | 100% |
| 14 | 6% | 15% | 70% | 100% |
| 15 | 6% | 15% | 30% | 50% |
| 16 | 6% | 15% | 70% | 50% |

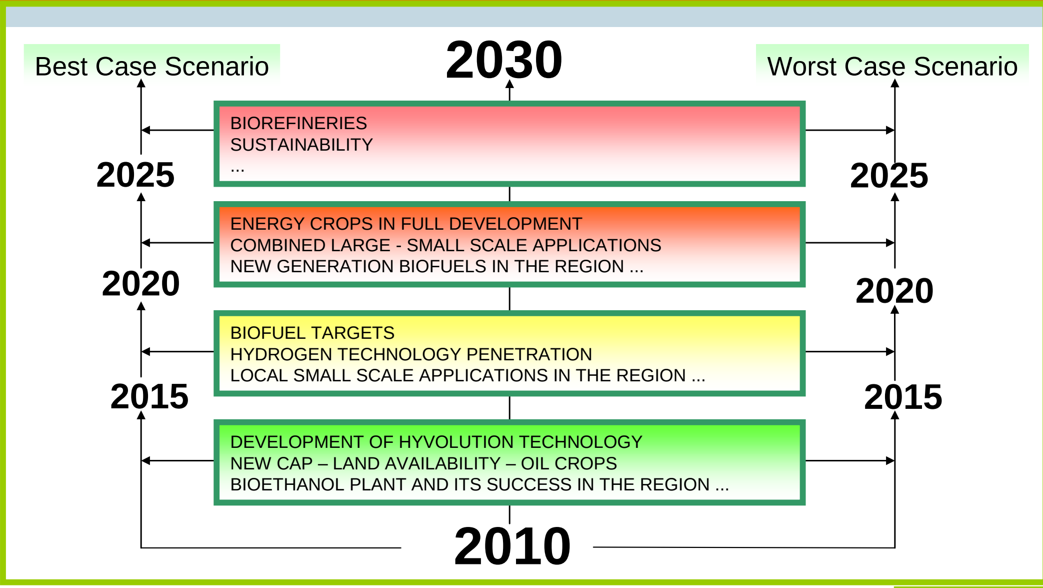
* 100% conversion = 0.1 t hydrogen from 1 t carbohydrates



# Stakeholders and policy aspects

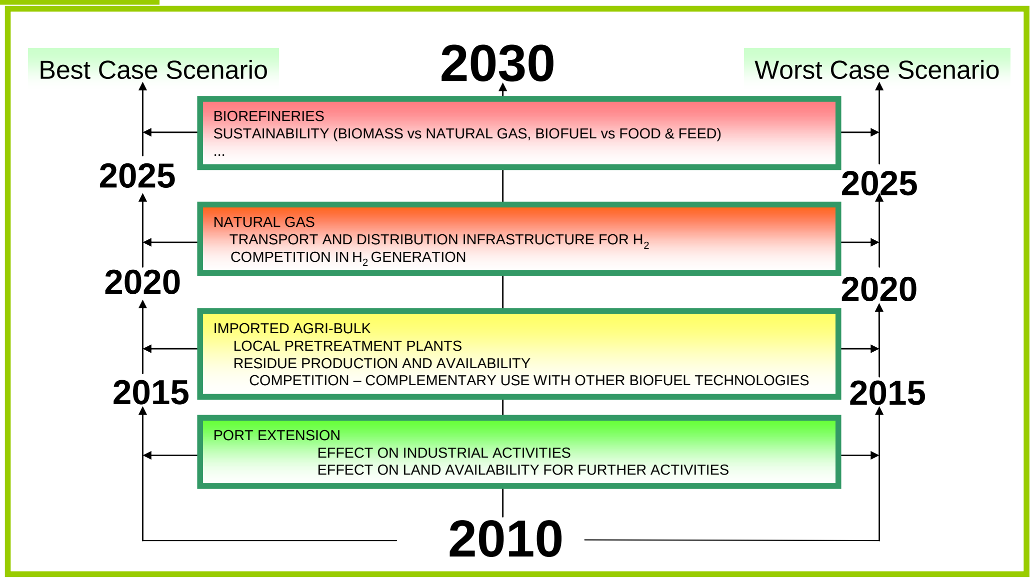


# Stakeholders and policy aspects




Rotterdam

Thessaly



# Concluding remarks

***General***

- Simultaneous research on the improvement of the hydrogen production efficiency and on the enrichment of the techno-economically suitable and sustainable feedstock portfolio should be carried out.
- It is assessed that the transition from first generation to second generation biofuels and  biohydrogen will play a crucial role for the land and infrastructure availability in both examined regions.
- Diverse effects of existing biofuel production plants on the development of Hyvolution technology:
  - Positive, in the “start-up” phase, providing the necessary infrastructure for pilot or small scale production
  - Possible negative effect in further development phase due to land use competition
  - “Success stories” of first generation biofuels will improve the social acceptance of biofuels and will create a “bio-society” culture which will facilitate the integration of Biohydrogen generation into the existing energy system

# Concluding remarks

***Thessaly***

- The social impact assessment of cotton culture replacement, in Thessaly, by energy crops should also consider the impact of this situation on the secondary sector, the cotton gin plants of the region, which employ a large number of labourers (about 200 permanent and 600 seasonal)

- The energy crop cultivation scenarios, even the most conservative ones, increase the potential significantly, increasing the importance of Thessaly in the future hydrogen economy, as well. According to the assumed "maximum energy crops" scenario in the region, 2.5 to 4.7% of the expected transport sector energy needs [EC - DG for Energy and Transport, 2007] (or 1.0 to 1.9% of the expected overall energy needs) of Greece in 2020 can be covered by the "Hyvolution" Hydrogen which will be produced in the region.

# Concluding remarks

***Rotterdam***

- The supply and demand site scenarios showed that the hydrogen demand of the region can be easily covered by the feedstock availability from the regional agro-industrial units, under the conditions that the continuous future development of these units is secured and that the techno-economic feedstock suitability issues for a larger number of potential Hyvolution feedstocks are solved.

- The land need for the reactor of the photochemical fermentation (currently 60ha for an 8000 dry tonne/year biomass plant capacity, estimation for 10 ha after process optimisation) is a further concern especially for Rotterdam case where the land availability is already limited.

# Thank you for your attention!