Aquatic phototrophs for the production of fuels and green chemicals

Dr. Luc Haspeslagh

EBTP 3SPM, 14 april 2010, Bruxelles

TOTAL

The Algae Advantage

- Algae grow in variable climates on <u>non arable land</u> with <u>non-potable water</u>

→ No competition with food crops

- Algae biomass is rich in <u>lipids</u>

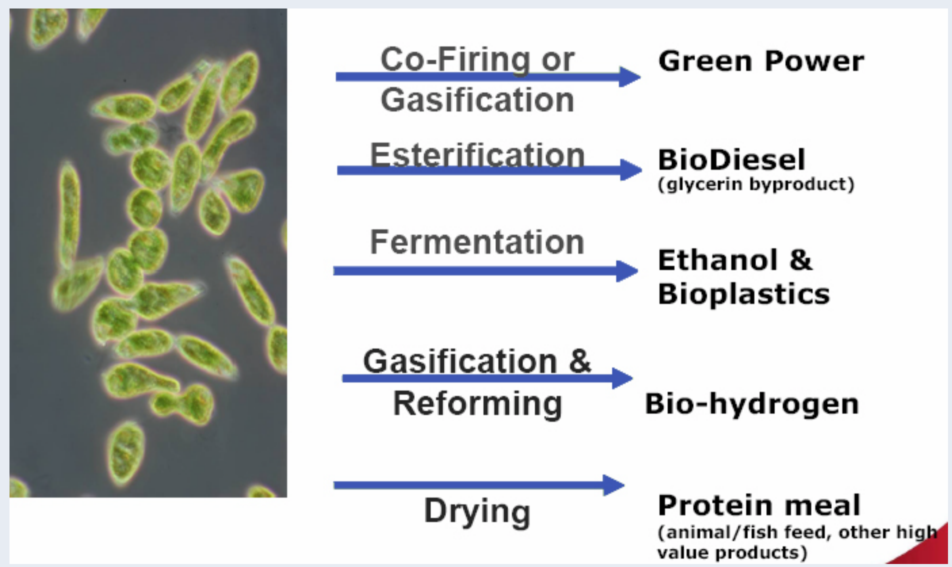
→ high energy density feedstock for fuels and chemicals

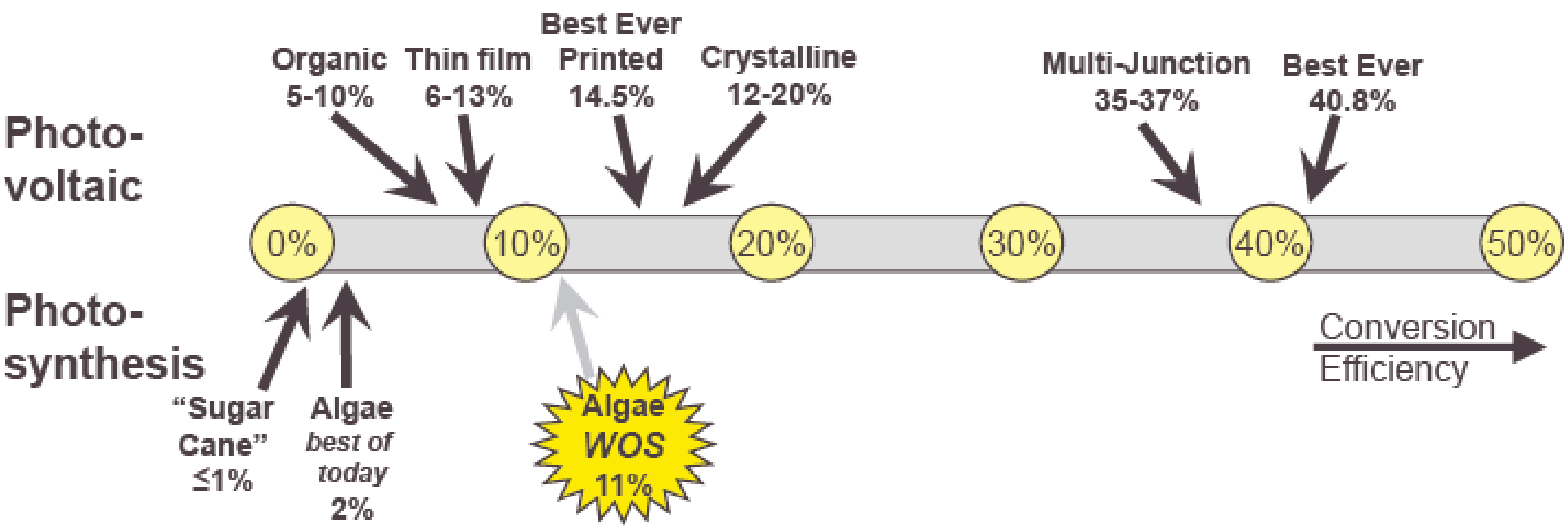
- Algae do <u>not</u> contain <u>lignin</u>

→ better adapted to biochemical valorisation

The Algae products

Dry biomass composition (Organic fraction)		
	Micro-Algae	*Grass*
Saccharides	5 - 25%	35%
Lipids	20 - 40%	3%
Proteins	20 - 50%	25%
Fibres (lignin)	-	37%





Photons + CO_2 + H_2O → Biomass + O_2

<u>CO2</u> abatement

<u>Molecules</u> for fuels and chemicals

Algae versus terrestrial biomass

Algae

- **Biomass production**

  Solar energy = 4000 Kcal/m²/day
  - @ 12% → 280 T/ha/y (50% lipids)
  - ***@ 2,5% → 70 T/ha/y (30% lipids)***

- **Lipid production**
  - @ 12% and 50% lipids → 155,000 l/ha/y
  - ***@ 2,5% and 30% lipids → 23,000 l/ha/y***

Terrestrial biomass

- **Biomass production**
  - Sorghum: 50 T/ha/y
  - ***Energy Cane: 75 T/ha/y***

- **Lipid production**
  - ***Palm oil: 6000 l/ha/y***
  - Rapeseed: 1400 l/ha/y
  - Sunflower: 950 l/ha/y

TOTAL

Development projects - Technologies

- **Ponds:**
  - Settling ponds of effluent management systems: Aquaflow Bionomic (New Zealar
  - Ocean based floating ponds: Sea Green (UK)
  - Open pond raceway: Live Fuels (USA) – Seambiotic (Israel) – Rincon Renewables (USA)
  - Closed ponds: Petrosun (USA) – Green Star Products (USA)

- **Confined photobioreactors:**
  - Plastic bags immerged in water ponds: Solix (USA)
  - Horizontal tubular: AlgaeLink (Neth.)
  - Vertical tubular and plate in greenhouses: Novagreen (Ger)
  - Vertical annular: BioFuel Systems (Spain)
  - Horizontal and vertical thin film in greenhouses: GreenFuel Technologies (USA)
  - Vertical plastic bags in greenhouses: Valcent Vertigro (USA)

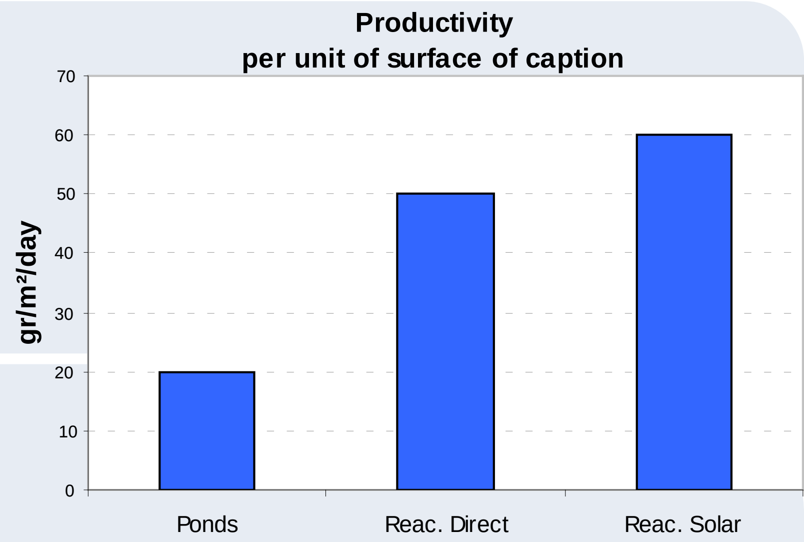
- **Multistage:**
  - Modular closed and open systems including stress stage: Petro Algae (USA)
  - ALDUO Technology: closed photobioreactor + open pond: HR Biopetroleum (USA)
  - Shamash (France)

- **Heterotrophous algae:**
  - Fermentation of sugars into algal biomass: Solazyme (USA) – Fermentalg (France)

State of the art

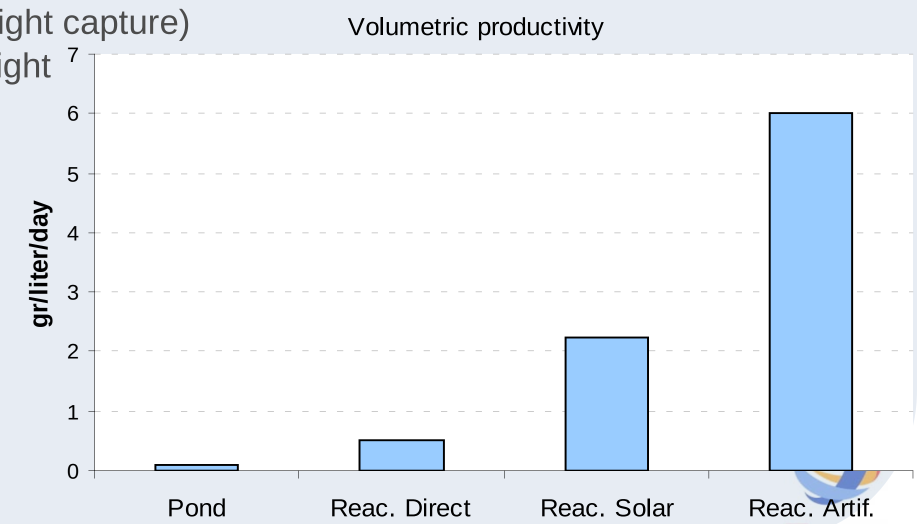
Ponds

- **Productivity**: 20 gr/m²/day of dry algal biomass = 70 T/ha/year
- **Capex**: $100,000 /ha
- **Opex**: $53,000 /ha/year
- **Pilot plants operating** (0,1 to 60 ha)
- Commercial units under construction (800 ha)
- NREL – Seambiotic – Live Fuels – PetroAlgae - PetroSun …



Confined photobioreactors:

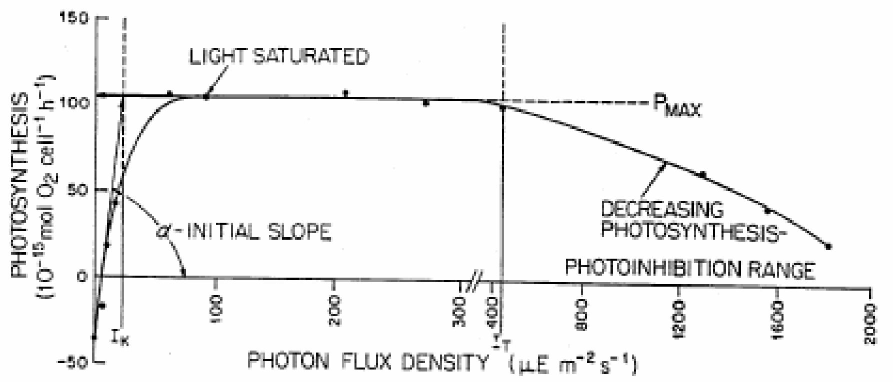
- **Productivity:**
  - Direct exposure:
    - 0.5 to 1.0 gr/l/day = 175 to 350 kg/m3/year
    - About 50 gr/m²/day = 175 T/ha/year
  - Direct exposure + internal lightning with captured solar light via optical fibers
    - 1.5 to 3.0 gr/l/day = 525 to 1050 kg/m3/year
    - About 60 gr/m²/day = 210 T/ha/year (surface of light capture)
  - Optimal lightning (external + internal) with artificial light
    - Up to 6 gr/l/day = 2100 kg/m3/year
- **Capex**: $0.5 to $3.0 million /ha
- **Opex:** significantly higher than for ponds
- **Pilot plants operating** (5000 liters)
- Demonstration units announced from 2009 on
- BioFuel Systems – AlgaeLink - Valcent Vertigro…



Confined photobioreactors: maximizing energy efficiency of algal photosynthesis

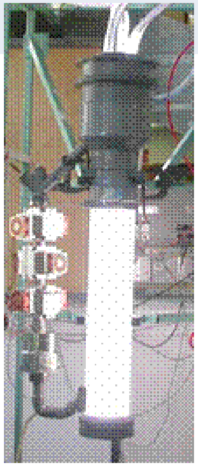
- Better control of parameters influencing the algae culture (temperature, pH, salinity etc…)
- Better control of gas transfer
- Better protection from outside contamination
- Higher densities
- Higher productivities
- Reduction in evaporation of growth medium
- Confined containers → use of GMO…
- Overcome light saturation effect
- …

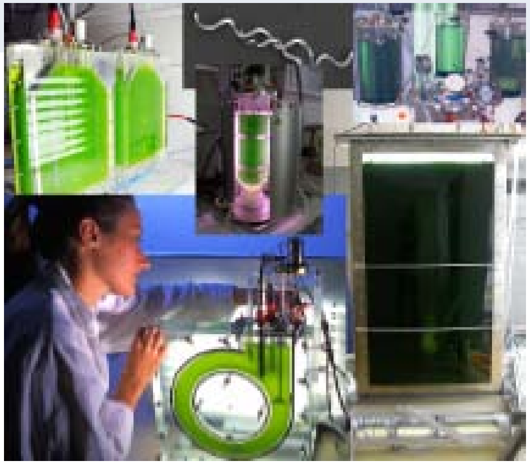
FIGURE 5.2.
THE PHOTOSYNTHESIS VS. LIGHT INTENSITY RELATIONSHIP
(Melis, unpublished)



But…

- Higher CAPEX
- Higher OPEX
- Reactor fouling
- …





Development projects – Business models

- **Predominant focus on end-product value and markets**
  - **Algal paste:**
    - Seambiotic – Solix – Valcent Vertigro
  - **Biocrude obtained after pyrolysis:**
    - BioFuel Systems
  - **Algal oil + delipidated algal cake:**
    - Algae Link – Green Fuel Technologies – Aurora – Live Fuels
  - **Algal oil + ethanol from remaining biomass:**
    - Petrosun – Green Star Products
  - **Biodiesel – Jet Fuel:**
    - Aquaflow Bionomic – Novagreen – Rincon Renewables – Sapphire Energy
  - **Algae oil for biofuels and other products + proteins for animal feed + carbohydrates for electricity and/or ethanol fermentation + residual biomass as solid fuel:**
    - HR Biopetroleum – Petro Algae

- **Very limited impact of CO2 mitigation credits**

TOTAL

Potential Business Models

- Selected business model will determine selection of technology
- Productivity remains an issue: surface – volume needed is high

Large scale production of algal biomass

- Focus on maximizing biomass production or maximizing lipid production…
- Technology: Aquaculture in ponds.
- Unit of 100,000 ton dry biomass / year →
  - State of the art (@ 20 gr/m²/day) = 1430 ha
  - Possible target (@ 50 gr/m²/day) = 570 ha
- Unit of 100,000 ton lipids / year →
  - State of the art (@ 20 gr/m²/day / 30% lipids) = 4760 ha
  - Possible target (@ 50 gr/m²/day / 50% lipids) = 1145 ha

  = 0.4% of TOTAL fuel production
- Competing technology: agriculture of terrestrial biomass

Capture and valorization of CO2 emitted by existing plant

- Focus on maximizing CO2 conversion
- Technology: Highly efficient confined photobioreactors
- Unit for conversion of 100,000 ton CO2/year →
  - State of the art (@ 2.25 gr/l/day) = 63 500 m3

    240 ha light caption surface
  - Optimal. (@ 6 gr/l/day) = 23 800 m3

    Using artificial light
- Integrate with waste water treatment

  = 0.2% of TOTAL CO2 emissions
- Competing technology: CCS

Oil Majors and Microalgae

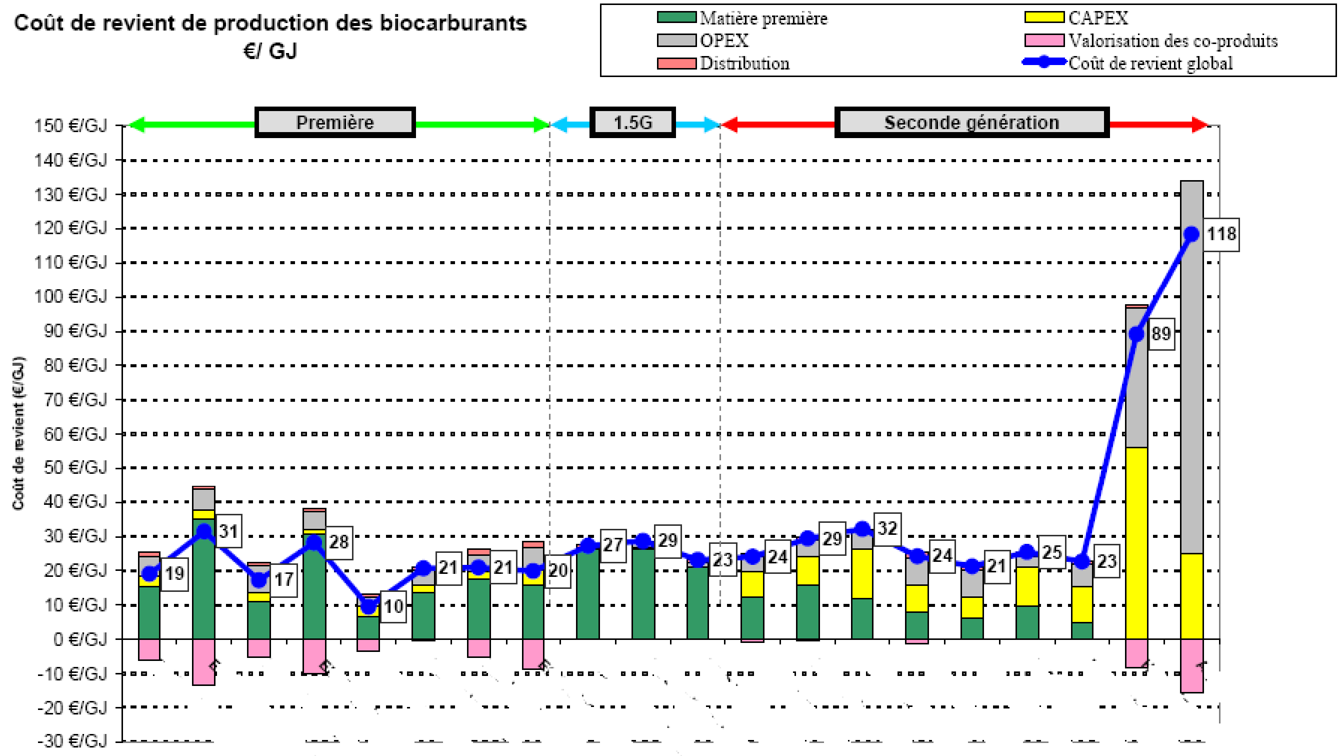
- **Shell**
  - Entered into JV with HR Biopetroleum to form Cellana (Hawaï)
  - Hybrid technology
  - Business model aiming at maximum valorization of all components of biomass produced (oil – proteins – carbohydrates – residuals)
  - Pilot facility under construction: 2.5 ha
- **EXXON**
  - M$600 R&D partnership with Synthetic Genomics for algal biofuels
  - SGI: GMO aqueous phototrophs – autosecretion – maximizing lipid production
  - Exxon: Process development
- **BP**
  - R&D program on cyanobacteria with ASU (stopped)
  - JDA with MARTEK (heterotrophous algae)

- **ENI**
  - At the origin of the International Network on Biofixation and Greenhouse Gas Abatement with Microalgae (since 2000)
  - Operating small scale pilot plants using both open pond and confined photobioreactor technology at Gela Refinery (Italy)
  - Preparing a larger scale demonstration project (2000 m² open ponds – 150 m² PBR)
- **Chevron**
  - R&D agreement with NREL to produce transportation fuels from algae – part of their five-year strategic biofuels alliance with NREL.
  - Cooperation with Solazyme (heterotrophous algae technology) without further details
- **Conoco Phillips**
  - $5 million Research agreement with Colorado Center for Biorefining and Biofuels on conversion of algae into renewable fuels

Main Challenges

- Reduce cost
- Improve energy balance
- Demonstrate process robustness both for scale and time.
- Master environmental risks

Reduce cost



- Current economics are <u>not compatible with a large volume low value added business model</u> for the production of fuels.
- Economics are strongly dependant on <u>valorization of co-products</u>: a feed-only business model has better economics than a fuel/feed business model.
- Overall biomass <u>productivity</u> per unit of surface area, <u>lipid content</u> per unit of biomass and biomass <u>concentration</u> in the culture are predominant leverage factors for reducing cost.
- <u>Smart engineering solutions</u> are needed to reduce capex over the integrated process chain.

Environmental risks

- **The production of aqueous phototrophs could present risk**
  - Development of uncontrolled seasonal blooms as a result of conditions of the environment like the presence of local nutrients
  - Irreversible changes to the ecosystem by invasive species

- **Define conditions in order to contain risks at an acceptable level both for protection of ecosystems as for human health**
  - Selection of strains
  - Protection at the level of the process: confinement – operating protocols
  - Protection at the level of the site

Research & Development challenges

- ***Biology: metabolics – management of ecosystems…***
  - What phototrophs to choose? (cyanobacteria – diatoms – micro-algae – macro-algae)
  - Maximize lipid production over cell growth in single stage process
  - Control lipid composition
  - Reduce nutrient consumption
  - Overcome reactor fouling
  - Auto-secretion of lipids
  - Assure robust production over longer periods of time
  - Avoid unwanted invasion of existing eco-systems.
  - …

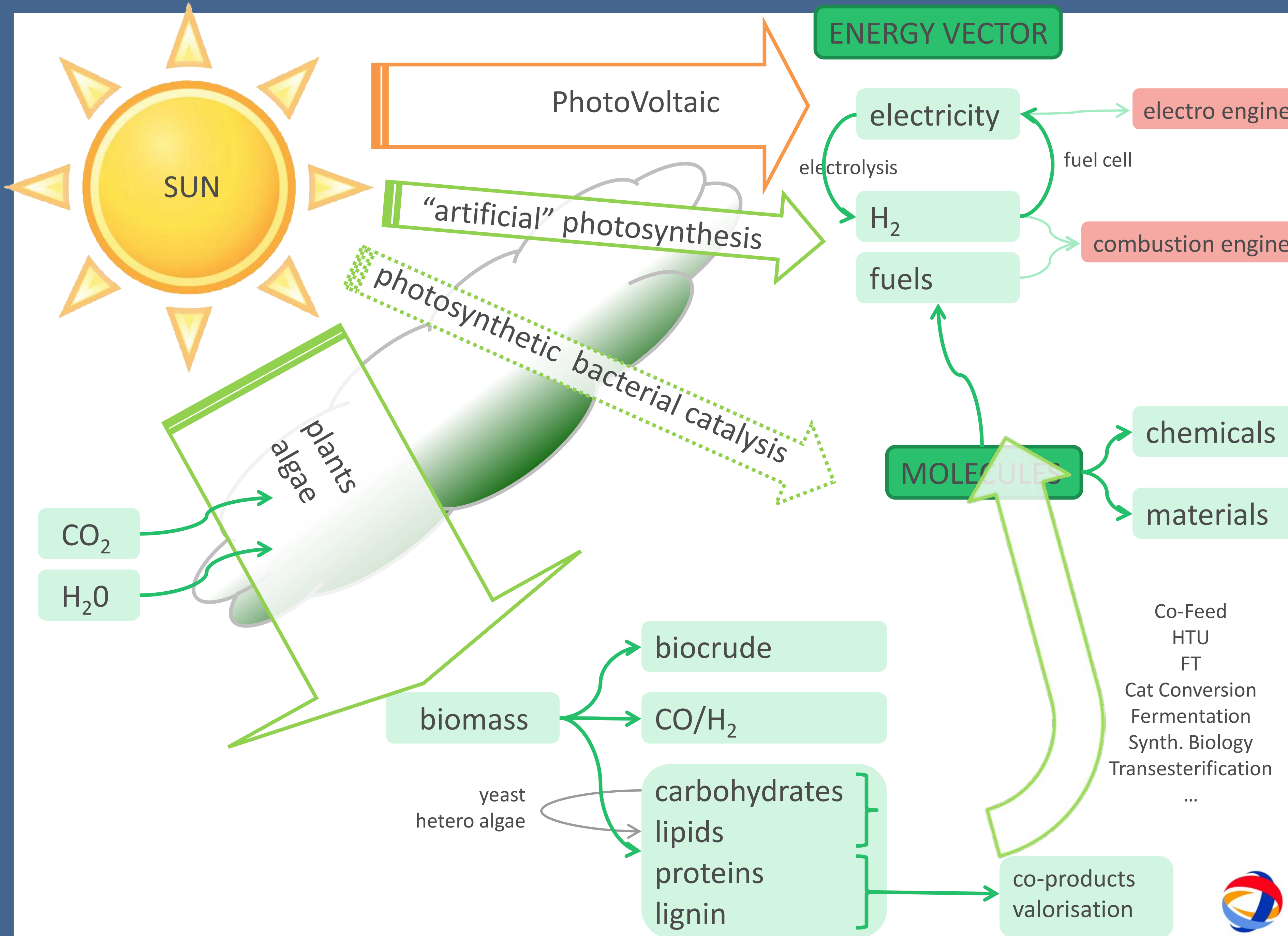
- ***Integrated process design:***
  - Improve tolerance to variations in composition and quality of entrants *(CO2 – water quality – nutrient sources…)*
  - Overcome limiting factors to achieve higher concentrations and productivities *(strain selection – process design and control – optimal interaction of light with biological system - modeling…)*
  - Reduce water consumption
  - Develop low-cost harvesting and extraction processes *(ultra-filtration – membrane technology – solvent extraction – cyclones…)*
  - Integrate valorizing processes *(waste water treatment – valorization of produced O2 …)*
  - Valorize co-products
  - Upscaling: advance the engineering of large scale production systems *(materials for photobioreactors – optical fibers – optimal light capture and transfer - avoid reactor fouling …)*
  - …

TOTAL

TOTAL approach

- ***Technology at R&D stage.***
- ***Clearly defined objectives direct the choice for technology options and the boundaries for the R&D program.***
  - *Screening of technical options for an integrated process, iusing an industrial CO2 source, non potable water, optimizing energy yield, minimizing environmental risks, offering economic competitiveness, targeting biofuels production, preferably bio kerosene.*
  - *Démontrate industrial feasibility .*
- ***Strong interplay between biology and process***
  - *Prospection for strong leading edge partnerships in biology*
  - *Technico – economic analysis to frame scope and identify high leverage issues*
  - *R&D platform for assessing and optimizing multiple technology options*
  - *Access and integrate innovative technology bricks from start-ups*

TOTAL


ENERGY VECTOR
SUN
PhotoVoltaic
"artificial" photosynthesis
photosynthetic bacterial catalysis
plants
algae
CO_2
H_2O
electricity
electro engine
electrolysis
fuel cell
H_2
combustion engine
fuels
MOLECULES
chemicals
materials
biomass
biocrude
CO/H_2
carbohydrates
lipids
proteins
lignin
yeast
hetero algae
co-products
valorisation
Co-Feed
HTU
FT
Cat Conversion
Fermentation
Synth. Biology
Transesterification
...