Micro-Algae

Forum Bioénergie ANR – PNRB

Paris – Feb 5 2009

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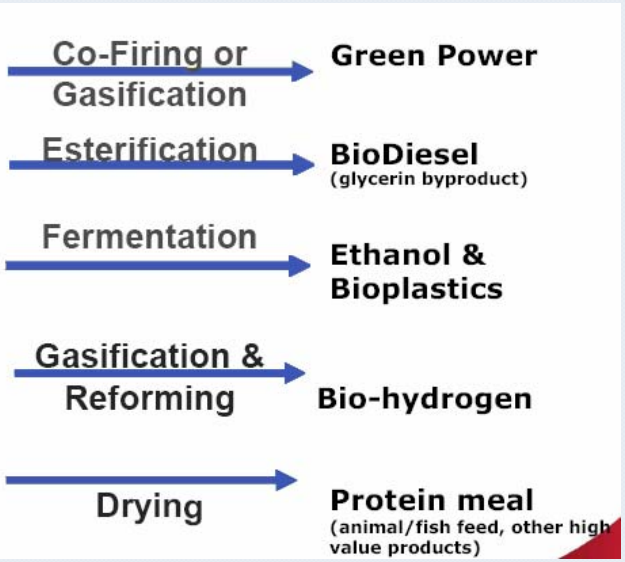
The Algae Advantage

- Algae are the most diverse and versatile biomass source
- Algae biomass is rich in lipids (>30%)
- Algae do not displace any food crops
- Algae grow in variable climates on non arable land with non-potable water
- Algae can be used for biofuel and energy production in various ways and technologies

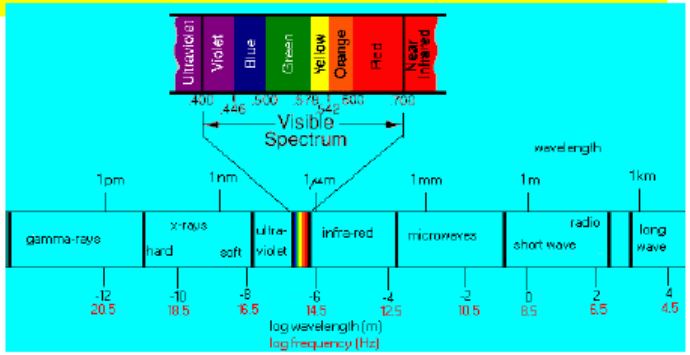
The Algae products

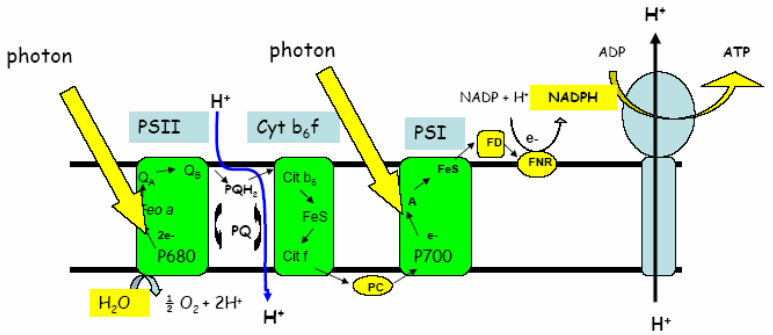
Dry biomass composition (Organic fraction)		
	Micro-Algae	*Grass*
Saccharides	5 - 25%	35%
Lipids	20 - 40%	3%
Proteins	20 - 50%	25%
Fibres (lignin)	-	37%



TOTAL

Only 45% of sunlight has the suitable wavelength (400 to 700 nm) (PAR) to drive (oxygenic) photosynthesis





- **8 photons** are required to fix one molecule of CO_2
- one mole of fixed CO_2 is equivalent to 475 KJ (1/6 mole glucose)
- PAR photons have average energy content of 217 KJ per mole

Thus:

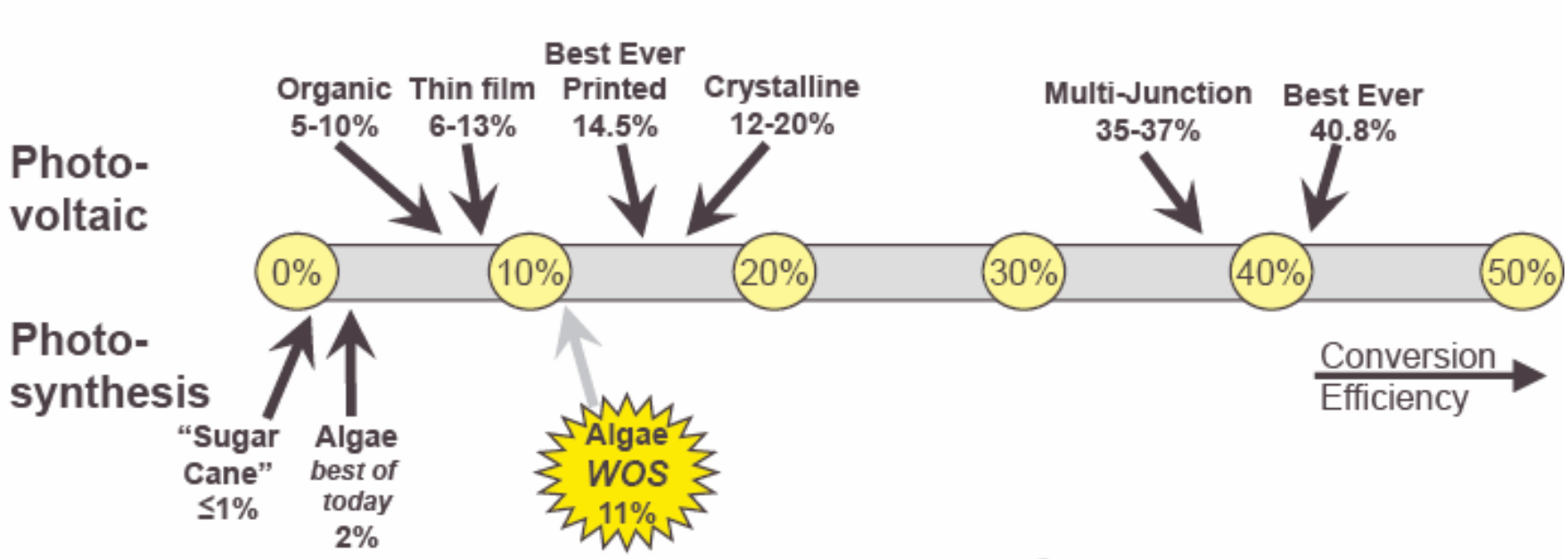
the maximum theoretical efficiency of conversion of PAR into the chemical energy of biomass is about 475 KJ / (217 x 8 KJ) = **27%**

The maximum conversion efficiency of total solar light by photosynthesis is:

→ 27% x 45% = 12%

<u>But</u>: further reduction by reflection losses, light saturation effect….

TOTAL



Photons + CO2 + H2O → Biomass + O2

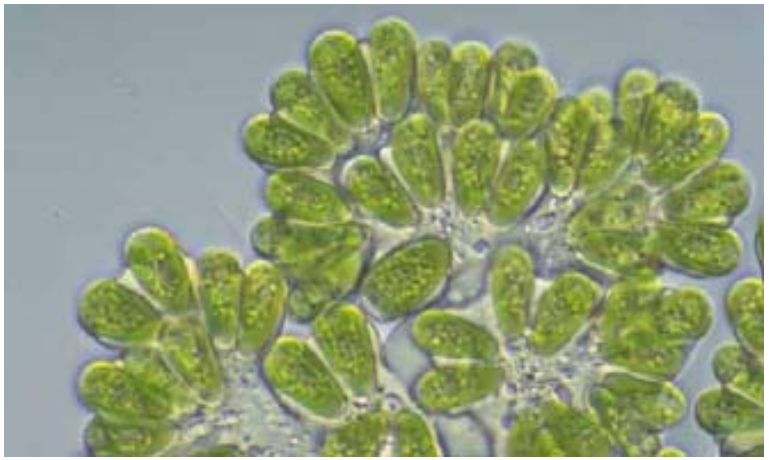
CO2 abatement
Molecules for fuels and chemicals

TOTAL

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

Algae Biofuel Companies

A2BE Carbon Capture, LLC
Algae Biofuels
Algae Link
Algenol (ethanol)
Algodyne
Algoil
Aquaflow Bionomic
Aquatic Energy
Aurora BioFuels Inc.
Bionavitas
Blue Biofuels
Blue Marble Energy
Bodega Algae
Cequesta
Circle Biodiesel & Ethanol
Community Fuels
Diversified Energy
Energy Farms
Enhanced Biofuels & Technologies
General Atomics
Global Green Solutions
Green Star
Greenfuel Technologies Corp
GreenShift (ethanol)
GS Cleantech
HR Biopetroleum/Shell (Cellana)
IGV
Imperium Renewables
Infinifuel Biodiesel
Inventure Chemical
Kai BioEnergy
KAS
Kent SeaTech Corp.
Kwikpower
LiveFuels, Inc.
Mighty Algae Biofuels
Oilfox
Organic Fuels
OriginOil
PetroAlgae
PetroSun
Phycal
Revolution Biofuels
Sapphire Energy
Seambiotic
SeaAg, Inc
Solazyme, Inc.
Solena
Solix Biofuels, Inc.
Sunrise Ridge Algae
Sunx Energy
Texas Clean Fuels
Trident Exploration/Menova
Valcent Products
W2 Energy
XL Renewables

Venture Capital Investments Heating Up

Venture Capital firms invested $280M in advanced biofuels (Q1-Q2 2008); $84 M for algae biomass; by comparison, $4M invested for algae Q3 2007

- **LiveFuels:** raised $10M Series A (2007)
- **Aurora BioFuels:** raises $20M; open-pond, algae oil production
- **Sapphire Energy:** raises $50M first round; additional $50M raised
- **Solazyme:** raises $45M; heterotrophic growth
- **Algenol Biofuels:** $850M from Mexico's BioFields; ethanol from Cyanobacteria
- **DOE:** announces $4.4M for six projects – two algae projects (Montana State Univ. & Univ. Georgia)

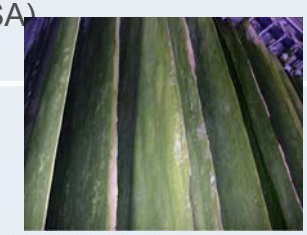
Development projects - Technologies

Ponds:

- Ocean based floating ponds: Sea Green (UK)
- Settling ponds of effluent management systems: Aquaflow Bionomic (New Zealand)
- Open pond raceway: Live Fuels (USA) – Seambiotic (Israel) – Rincon Renewables (USA)
- Closed ponds: Petrosun (USA) – Green Star Products (USA)
- Plastic bags immerged in water ponds: Solix (USA)

Confined photobioreactors:

- 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:

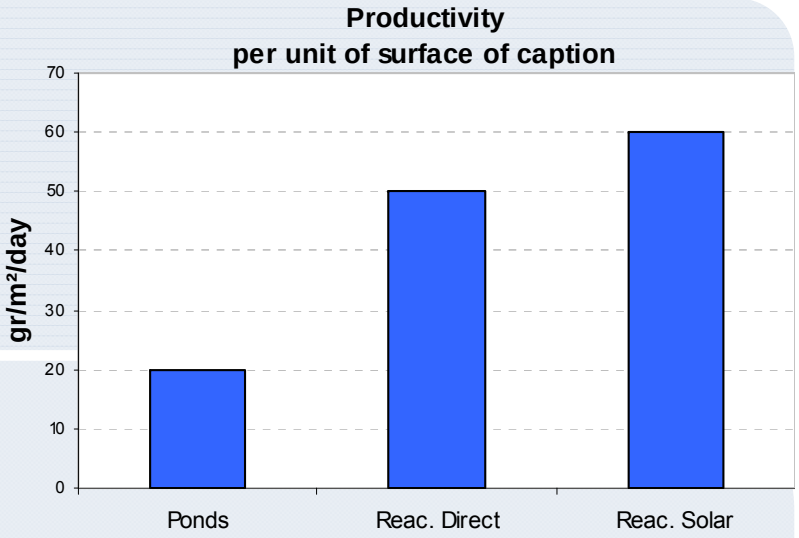
- Fermentation of sugars into algal biomass: Solazyme (USA) – Fermentalg (France)

TOTAL

State of the art

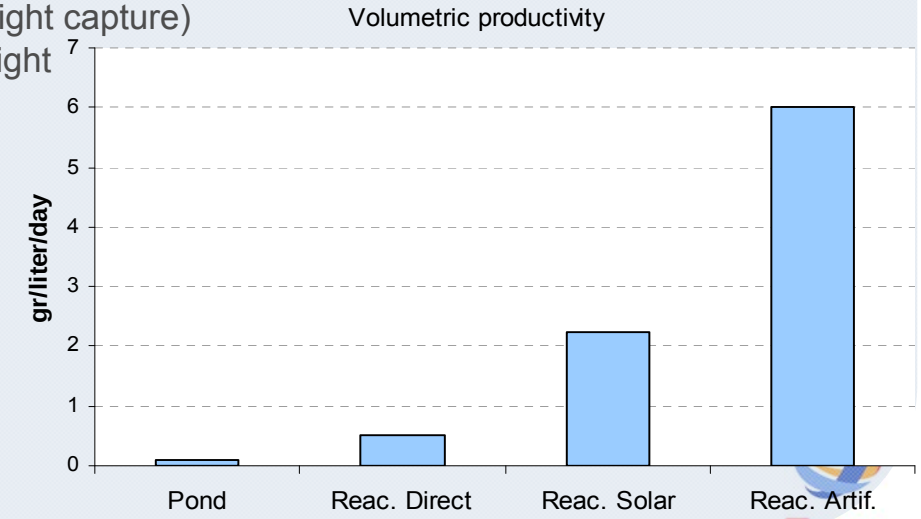
Ponds

- **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 …



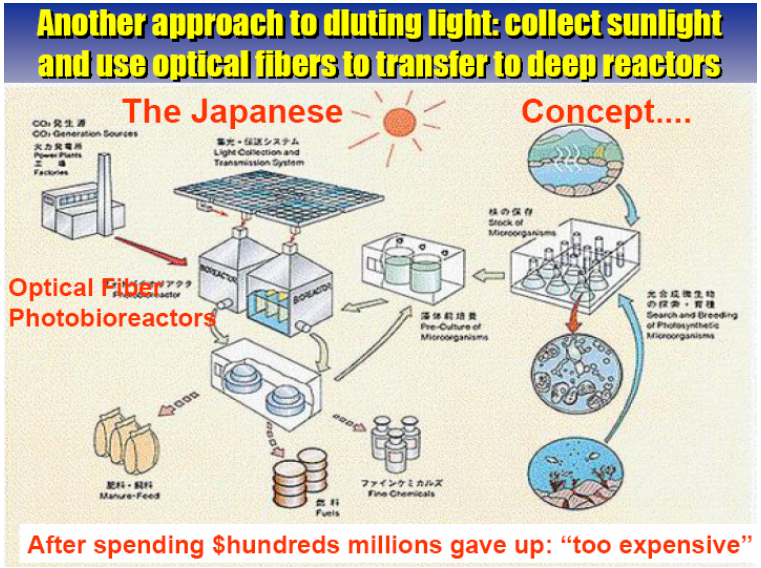
Confined photobioreactors:

- **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…

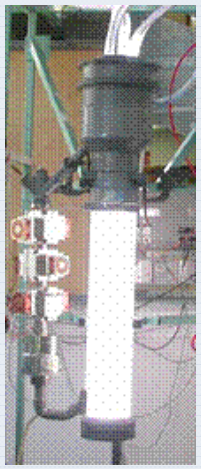


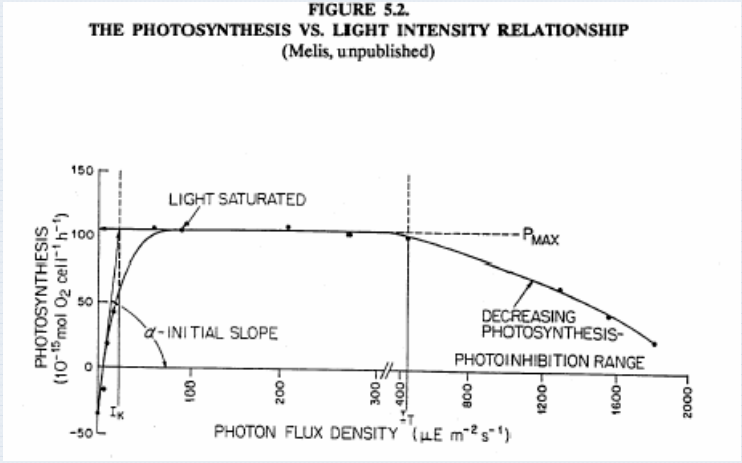
Confined photobioreactors…

- Higher CAPEX
- Higher OPEX
- Reactor fouling
- …



- **But…**
  - 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
  - …





TOTAL

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 to a large extend,
R&D objectives, scope and partners

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

- **Large scale production of algal biomass:**
  - **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
  - **Shell**
    - Entered into JV with HR Biopetroleum to form Cellana (Hawaï)
    - Hybrid technology using confined photobioreactors in first stage and open pond systems in second stage
    - Business model aiming at maximum valorization of all components of biomass produced (oil – proteins – carbohydrates – residuals)
    - Pilot facility under construction: 2.5 ha
  - **Conoco Phillips**
    - $5 million Research agreement with Colorado Center for Biorefining and Biofuels on conversion of algae into renewable fuels

- **Integration into industrial units for CO2 valorization:**
  - **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)

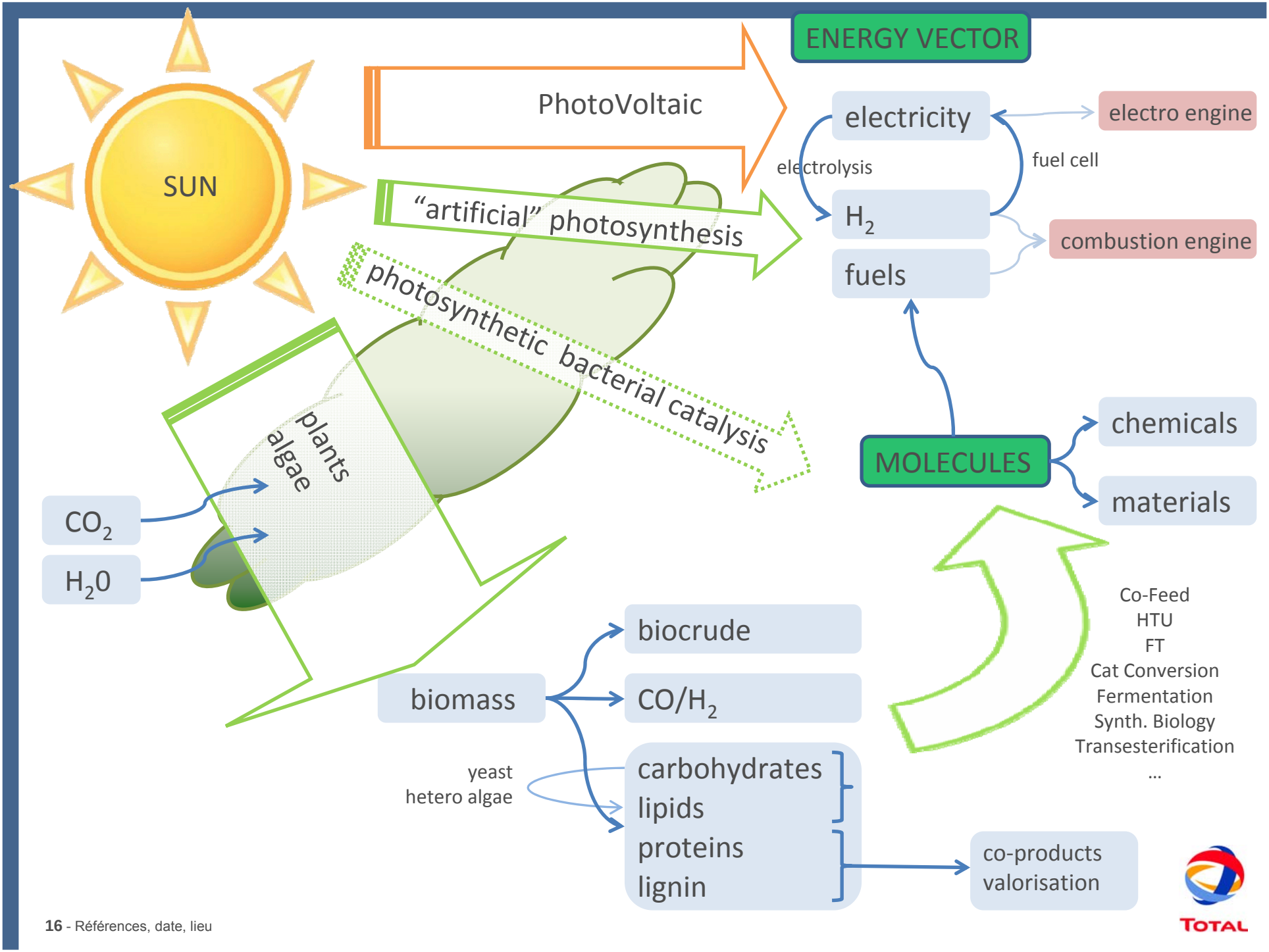
Main Challenges

- Reduce cost
- Improve energy balance
- Demonstrate robust large scale operation over longer time

Research & Development challenges

- Obtain and/or develop **algae strains** that allow robust production over longer time periods in a selected process and environment, yielding biomass with optimal composition for the targeted business model. *(selection – genetic modification…)*
- Overcome limiting factors to achieve higher **concentrations** and **productivities** *(strain selection – process design and control – optimal interaction of light with biological system - modeling…)*
- Control and master process conditions to assure **robust production** over longer periods of time *(strain selection – sanitation protocols – management of ecosystems – closed systems …)*
- Improve tolerance to variations in **composition and quality of entrants** *(CO2 – water quality – nutrient sources…)*
- Develop low-cost **harvesting and extraction** processes *(ultra-filtration – membrane technology – solvent extraction – cyclones…)*
- Integrate **valorizing processes** *(waste water treatment – valorization of co-products …)*
- Advance the **engineering** of large scale production systems *(materials for photobioreactors – optical fibers – optimal light capture and transfer - avoid reactor fouling …)*

TOTAL


ENERGY VECTOR
SUN
PhotoVoltaic
electricity
electro engine
electrolysis
fuel cell
"artificial" photosynthesis
H_2
combustion engine
photosynthetic bacterial catalysis
fuels
plants
algae
MOLECULES
chemicals
materials
CO_2
H_2O
Co-Feed
HTU
FT
Cat Conversion
Fermentation
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carbohydrates
lipids
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