

Aquatic phototrophs for the production of fuels and green chemicals

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Références, date, lieu

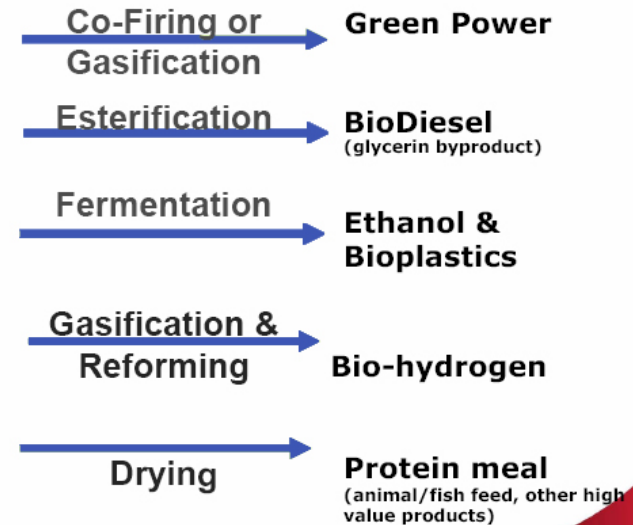
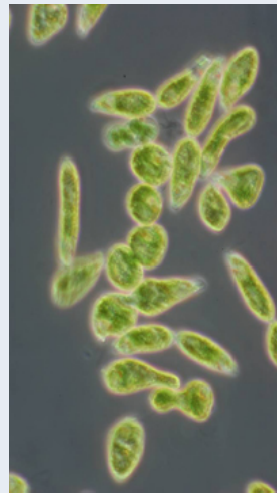


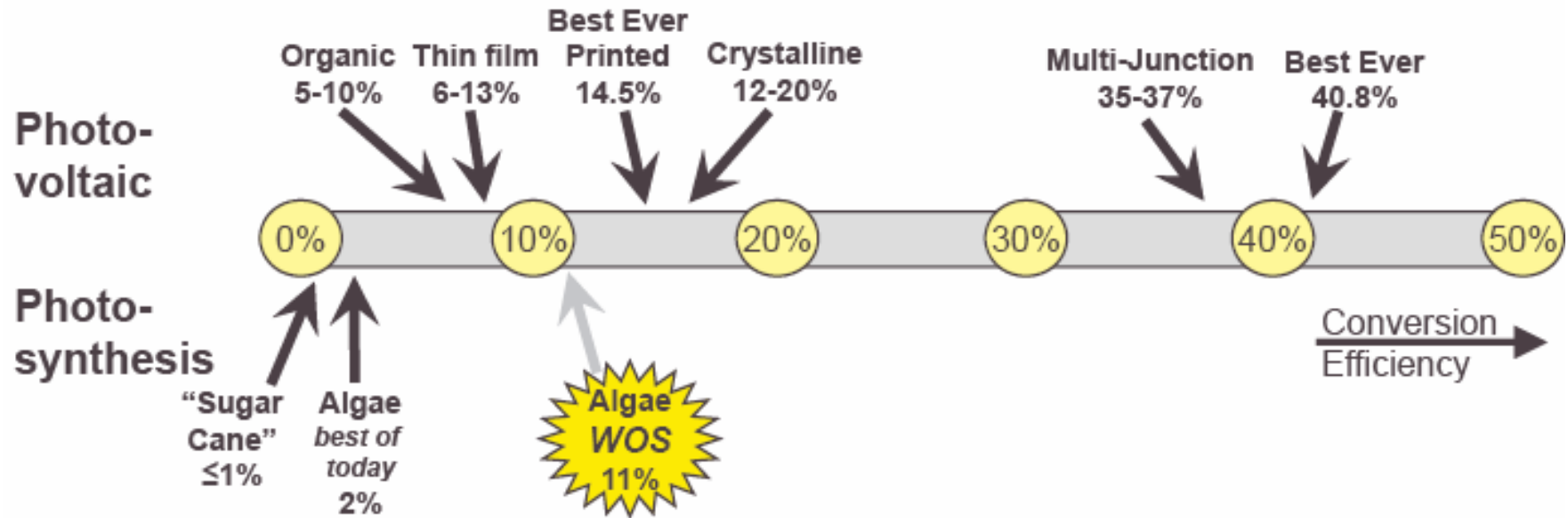
The Algae Advantage

- ▶ Algae grow in variable climates on non arable land with non-potable water
 - No competition with food crops
- ▶ Algae biomass is rich in lipids
 - high energy density feedstock for fuels and chemicals
- ▶ Algae do not contain lignin
 - 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%





CO₂ abatement
Molecules for fuels and chemicals

Algae versus terrestrial biomass

Algae

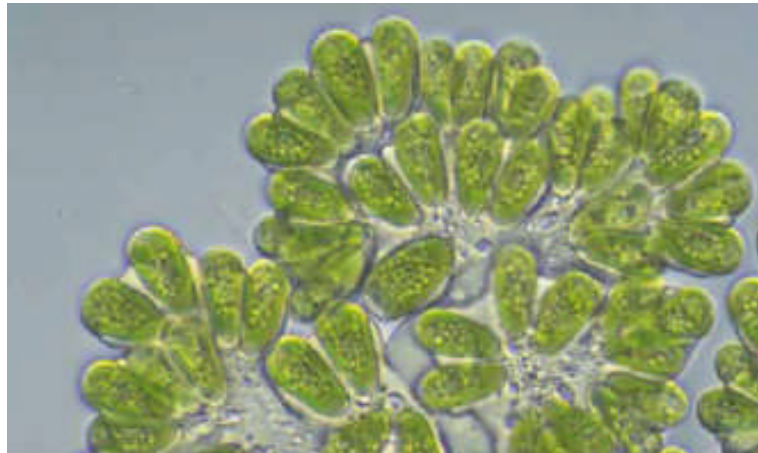
► Biomass production

Solar energy = 4000 Kcal/m²/day

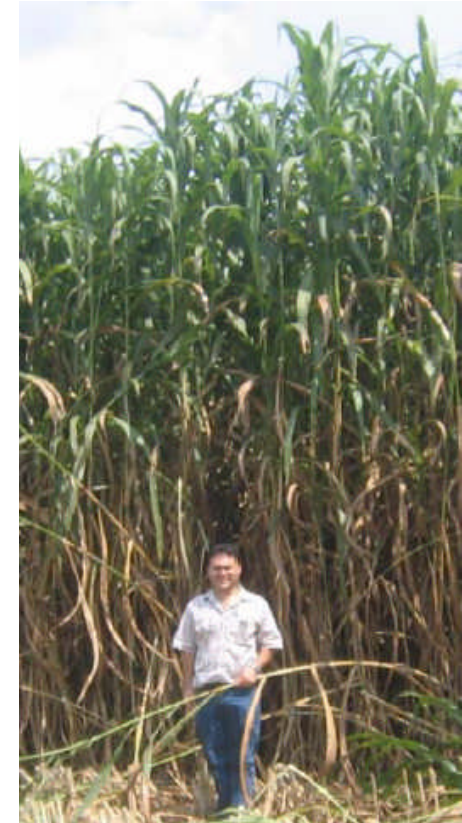
- @ 12% → 280 T/ha/y (50% lipids)
- @ 2,5% → 70 T/ha/y (30% lipids)

► 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*

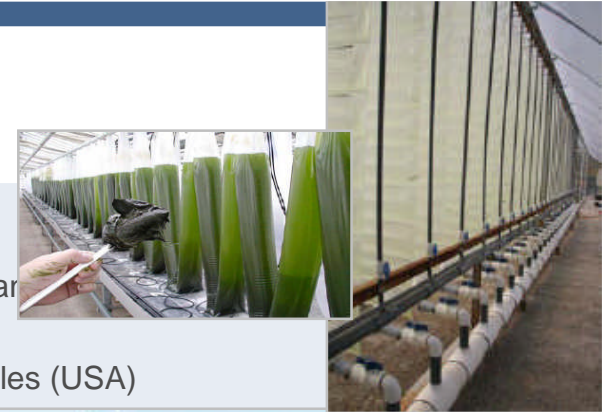
► Lipid production

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

Development projects - Technologies

► Ponds:

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



► Confined photobioreactors:

- Plastic bags immersed 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 Vertigo (USA)



► Multistage:

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



► Heterotrophic algae:

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



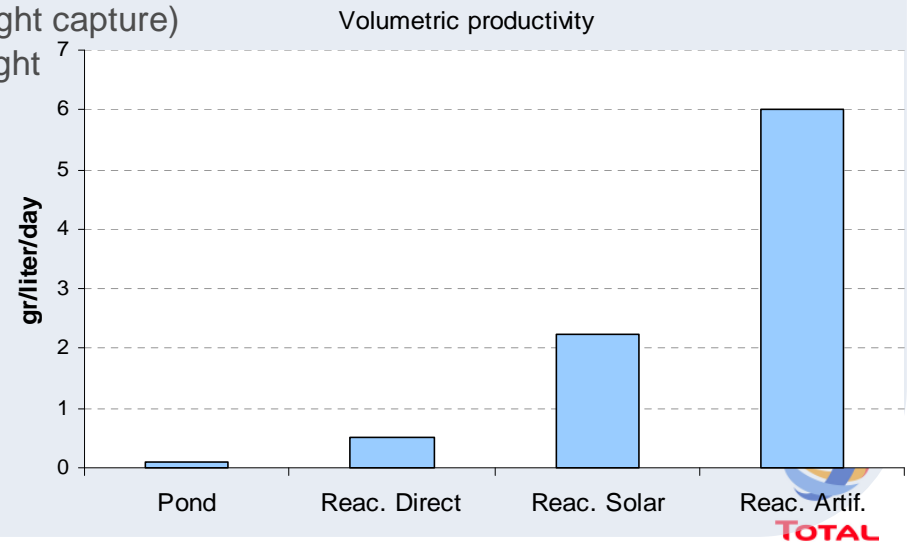
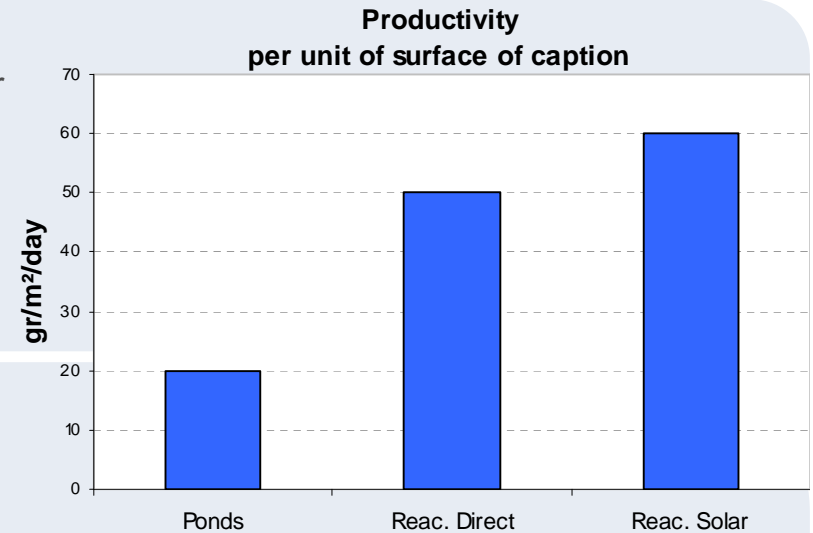
State of the art

▸ 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...

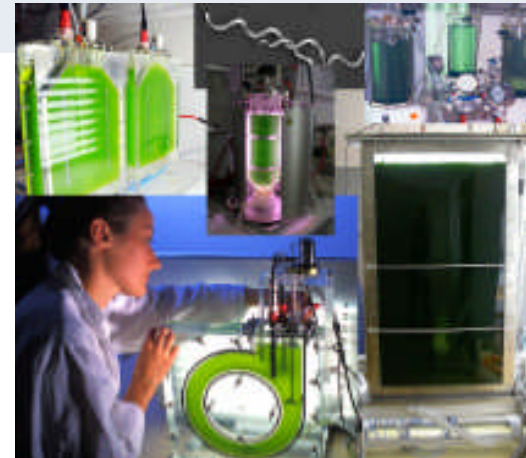
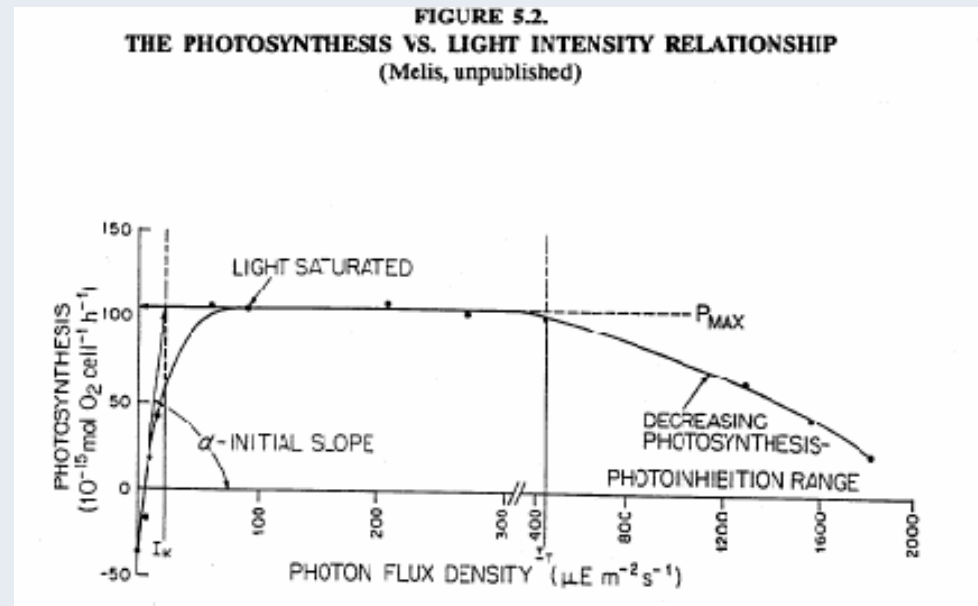


Confined photobioreactors: maximizing energy efficiency of algal photosynthesis

- 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
- ...

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:**
 - Aquaflo 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



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



9 - Références, date, lieu

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 (Hawai)
- 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 (heterotrophic algae)

▪ ENI

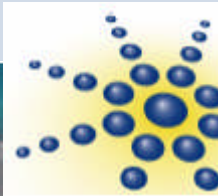
- At the origin of the International Network on Biofixation and Greenhouse Gas Abatement with Microalgae (since 2000)
- Operating small scale pilot plants using both open pond and confined photobioreactor technology at Gela Refinery (Italy)
- Preparing a larger scale demonstration project (2000 m² open 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 (heterotrophic algae technology) without further details

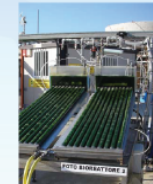
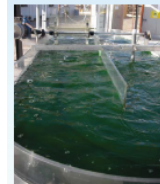
▪ Conoco Phillips

- \$5 million Research agreement with Colorado Center for Biorefining and Biofuels on conversion of algae into renewable fuels



CO₂ Biofixation And Vegetable Oil Production From Microalgae

Bench Scale Plant at Gela Refinery



Eni's Way



TOTAL

Main Challenges

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

Reduce cost

- ▶ Current economics are not compatible with a large volume low value added business model for the production of fuels.
- ▶ Economics are strongly dependant on valorization of co-products: a feed-only business model has better economics than a fuel/feed business model.
- ▶ Overall biomass productivity per unit of surface area, lipid content per unit of biomass and biomass concentration in the culture are predominant leverage factors for reducing cost.
- ▶ Smart engineering solutions 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 interest in aquatic phototrophs

- ▶ From petroleum company to energy provider: bio-energy is one of the strategic axes aside from solar and clean coal.
- ▶ Renewable resources for petrochemistry and specialty chemistry
- ▶ Aquatic biomass versus terrestrial biomass:
 - No need for arable land, but still large surfaces needed.
 - No need for potable water, but still large volumes of water needed.
 - Nutrients balance versus fertilizers...
 - Up to 5 times higher lipid productivity per surface area
 - Produces biomass without lignin
 - Aquaculture is much less mature than agriculture
- ▶ Mono-cellular aquatic phototrophs hold promise to maximize energy efficiency from photosynthesis.

TOTAL approach

- ▶ *Technology at R&D stage.*
- ▶ *Clearly defined objectives direct the choice for technology options and the boundaries for the R&D program.*
- ▶ *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*

