TOTAL
COMMITTED TO BETTER ENERGY

AMYRIS

## FUELS WORKSHOP CASE STUDY #1:

# DEVELOPING AND COMMERCIALIZING RENEWABLE BIO-JET FUEL


Vineet Rajgarhia

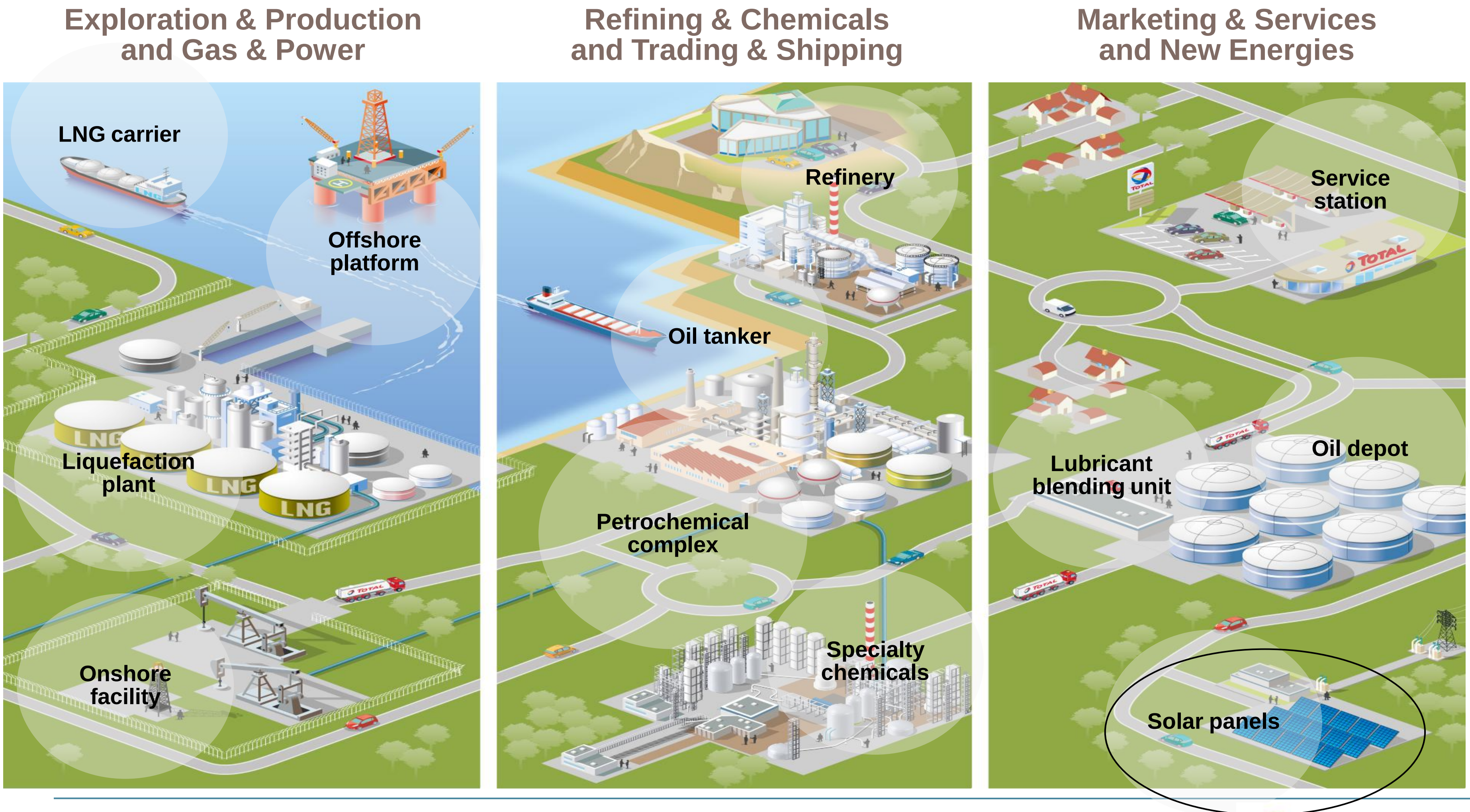
*VP Biotechnology R&D*

*Total New Energies, USA*


# AGENDA

- A little on Total, SA and Total New Energies
- The Energy mix expected to meet the need of the world in 2035 and GHG challenges
- Total's commitment to better energy and our choice of Solar and Biotechnology
- Our partnership with Amyris and Renewable Bio-Jet Fuel
- Development of Farnesane as a renewable jet fuel
  - Jet Fuel
  - Certification Process
  - Challenges of Developing competitor to fossil jet fuel
  - Current Status
  - Future outlook

# NEW ENERGIES IN OUR GLOBAL AND DIVERSE OPERATION



# OUR KEY INDICATORS IN 2014



MORE THAN **700**
PRODUCTION FACILITIES

**$12.8 bn***
ADJUSTED NET INCOME

* €9.7bn

**$7.39 bn**
ALLOCATED TO R&D
*between 2015 and 2019*

**$236.1 bn***
REVENUE

* €177.7bn

**100,307**
EMPLOYEES

**$26.4 bn***
ORGANIC INVESTMENT

* €19.9bn

* Employees on the payroll as of Dec. 31, 2014

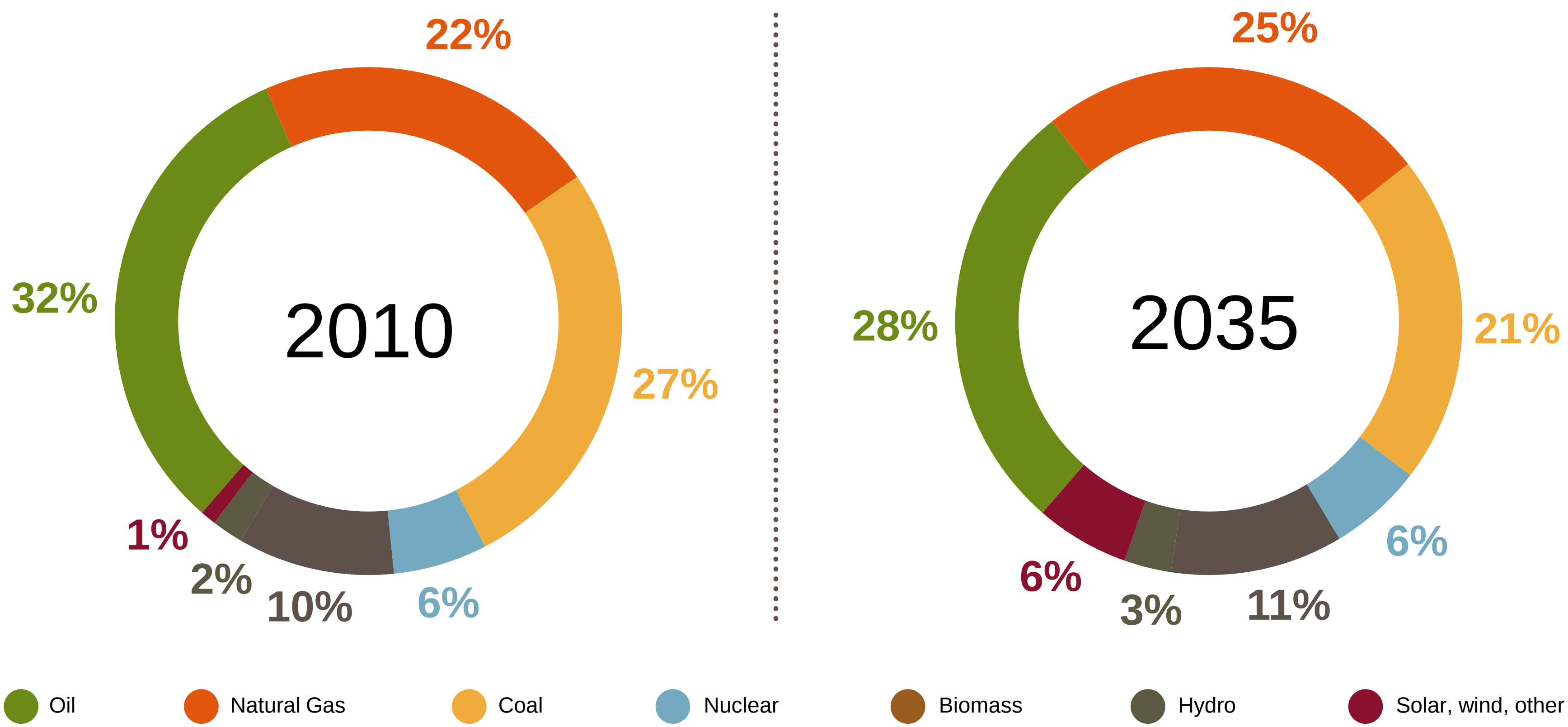
# OUTLOOK FOR ENERGY DEMAND



| | POPULATION GROWTH billion people | ECONOMIC GROWTH $ trillion in 2011 (GDP in purchasing power parity) | HIGHER ENERGY DEMAND million barrels of oil equivalent per day |
|---|---|---|---|
| 2010 | 7 | 75.2 | 265 |
| 2035 | 8.5 | 175.7 | 349 |

Sources: UN, IMF, Total, IEA - January 2013

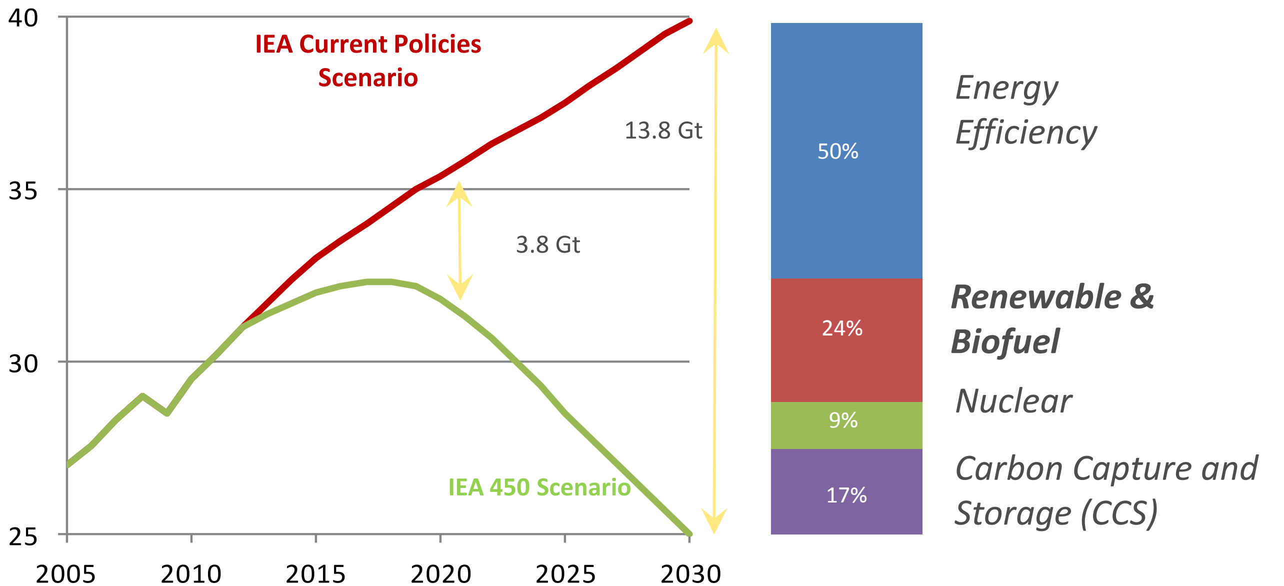
# OUR VISION OF GLOBAL ENERGY DEMAND IN 2035




- **Fossil based energies still represent 74% of energy supply in 2035**
- **Gas to become the second largest energy source before 2030**
- **Very strong growth of new energies, in particular of solar energy and biomass**

# TOTAL'S COMMITMENT TO BETTER ENERGY

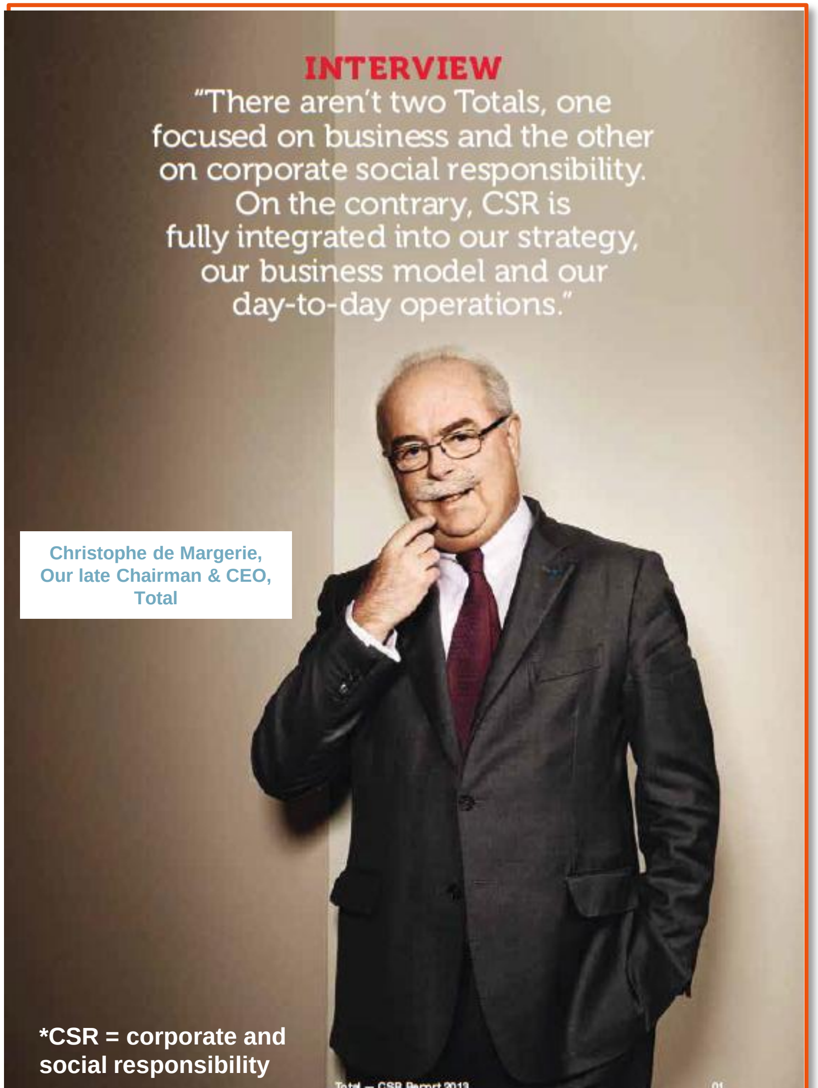
## Global Climate Change - $CO_2$ emissions (Gt)




*Source : International Energy Agency (IEA) World Energy Outlook 2010*

Under the IEA 450ppm scenario **renewable energy is the 2nd most important way to reduce $CO_2$.** Maintaining "status quo" (redline in graph) inadvisable option

# TOTAL'S COMMITMENT TO BETTER ENERGY: TWEAKING INTERNAL OPERATIONS AND VIA INNOVATION




Christophe de Margerie, Our late Chairman & CEO, Total

*CSR = corporate and social responsibility

## Thinking Ahead

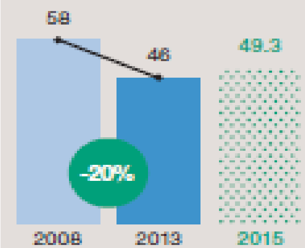
**€25**

**per ton** is the carbon cost assumption applied to our projects, prior to any investment decision, to measure their carbon footprint over the long term and their continued profitability in the event of changes to carbon markets.

## GREENHOUSE GAS EMISSIONS

**Objective:** Reduce greenhouse gas emissions by 15% between 2008 and 2015 in our operated scope.

**⊕ On track to meet target ahead of schedule**




In million tons of carbon dioxide equivalent.

## Successful Miaden Flights for Biojet Fuel

In June 2013, an Airbus A321 made a successful Toulouse-Paris flight using fuel containing **Total-Amyris A-1 biojet**, manufactured from sugarcane. This success was confirmed by a demonstration flight in Abu Dhabi in January 2014. Developing biofuels to help airlines reduce their carbon dioxide emissions is one of the objectives of our R&D programs with Amyris. Total has been the core shareholder in the company since June 2010, and our long-term goal is to produce biofuels from lignocellulose, the non-food part of plants. In late 2013, Total set up a joint venture with Amyris to produce and market renewable fuels worldwide.

## Flagship Solar Projects in the United States

In California, SunPower has completed construction of the California Valley Solar Ranch, which has generating capacity of 314 MWdc, and has started building Solar Star, the world's biggest solar power plant. With 709 MWdc of installed power, Solar Star will generate enough electricity to power around 255,000 homes.

# THE VISION CONTINUES WITH NEW TOTAL LEADERSHIP

The Executive Committee articulated Total's **vision** in 2011 and updated it in 2014. "Our vision is to be a global, integrated energy company — a leading international oil company and a world-class operator in gas and solar energy." This year we added the following sentence to reflect our new "Committed to Better Energy" signature: "We want to be the company whose actions inspire confidence in a responsible energy future."

But we do have "Committed to Better Energy." Maybe it can bridge this gap if we work together to turn it into a genuine **enterprise project.** In his address to managers at the Les Docks Convention in March 2014, Christophe said: "It's not a communication gimmick; it's a corporate position."



TOTAL COMMITTED TO BETTER ENERGY

# COMMITMENT TO BETTER ENERGY VIA INNOVATION

**Leadership in solar energy** and **biotechnologies to address Total's energy & chemical markets**

## A leader in solar power

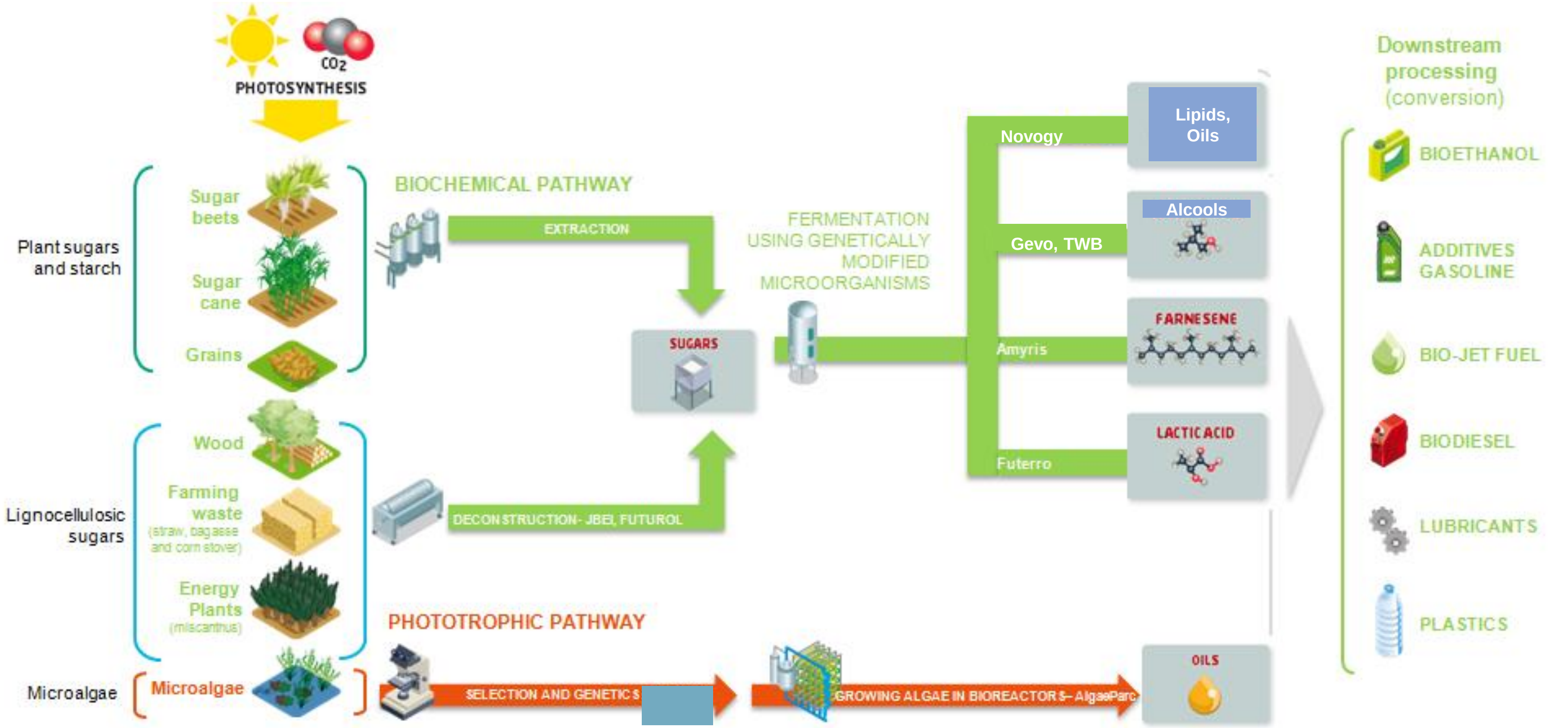
- Be a **global leader -** SunPower, >66% ownership
- **Technological leadership** in solar through cutting-edge R&D and manufacturing excellence
- Be present across the **photovoltaic value chain**

## Produce bio-molecules for Total markets

- **Differentiate through technology development – accelerate innovation via partnership model**
- **Use Total's existing capex infrastructure – find synergies in Total markets**
- **With an environmentally and socially** sustainable approach

# VISION: FROM $CO_2$ TO PRODUCTS

- Back in 2010, strategic decision to focus on **plant-to-sugar-to-commodities**:
  - Step 1 - Hydrocarbons from sugars
  - Step 2 - **Lignocellulose** to access to non food/feed and inexpensive sugars




TOTAL opted for an open-innovation model and has established a collaborative network in each segment of the value chain

# TOTAL-AMYRIS PARTNERSHIP SINCE JUNE 2010

- Develop the **whole value chain** integrated from biomass to finished products

**Biomass** —**Pre-treatment**→ **Fermentable raw materials** —**Fermentation**→ **Molecules $C_iH_j$** —**Downstream Processing**→ **Products**

## Feedstock sourcing

- 1st generation in Brazil on sugar cane
- **Leading to 2nd generation**

## Synthetic biology

- Bio-engineering of micro-organisms
- R&D network

## Fermentation and chemical processes

- Track record for strain improvement
- Scale-up and industrial chemistry

## Trading & marketing

*Fuels* *Special fluids Lubricants Chemicals*

- Competitive molecules
- Access to markets

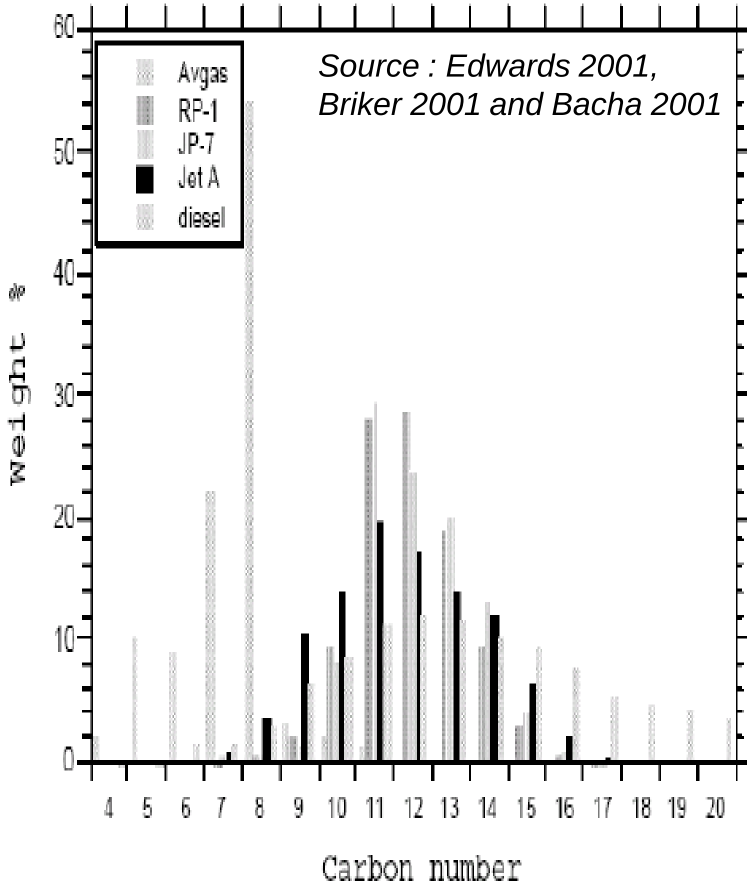
- **Strategic alignment**: Total has major ownership of Amyris capital

**The development of a renewable bio-jet fuel was the first joint program**

# RENEWABLE JET FUEL OPPORTUNITY

# WHAT IS A JET FUEL?

- Most widely used jet fuel: Jet A / A-1 for commercial civil aviation
  - Defined and specified in ASTM Standard D1655
  - *Complex mixture of hydrocarbons and varies depending on crude source*
  - *Performance specification rather than a compositional specification.*
  - *Largely relied on accumulated experience*
  - *kerosene cut between* lighter gasoline and heavier diesel cuts




Jet A / A-1 is a distribution of C8 to C16 hydrocarbons



TOTAL

# KEY SPECIFICATIONS OF JET FUEL

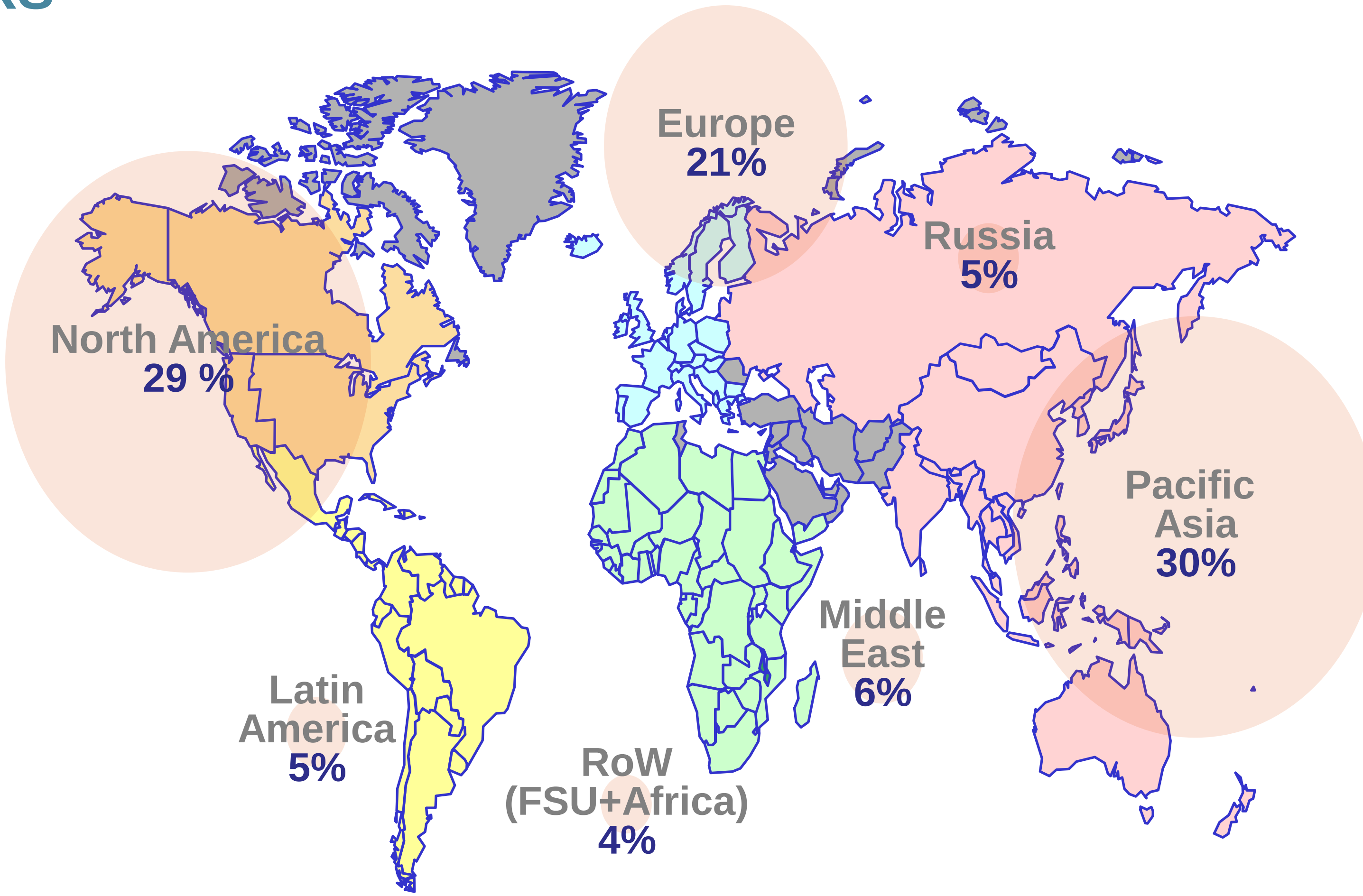
- **21 performances and properties** must be met
- This allows a strict control on the **quality**
  - Flash point (prevention of explosions in fuel handling and tanks)
  - Energy content (aircraft range)
  - Freeze point (ability to pump fuel at low temperature)
  - Thermal stability (prevention of fuel system / nozzles clogging or fouling)
  - Viscosity (ability to spray fuel and to relight at high altitude)
  - Lubricity (ability to lubricates fuel system / engine control)
  - Combustion (prevention of particles formation)
  - Material compatibility (prevention of the degradation of metals, polymers and elastomers the fuel is in contact with)

Jet A / A-1 is controlled by feedstocks, processes and properties that guarantee safe and satisfactory operations of aircraft and engines



TOTAL

# JET FUEL MARKET: STEADY GROWTH FOR THE NEXT 15 YEARS




*Source : Passengers World Traffic (ICAO 2013)*

Demand for air transport will grow x2 in the next 15 years, driven by Asia
Steady growth rate of +1.6%/year

# CHALLENGES TO DEVELOPING AND COMMERCIALIZING RENEWABLE JET FUEL

# FOUR CONSTRAINTS TO COMMERCIALIZE RENEWABLE JET FUEL

- **Safety**: renewable jet fuel has to be innocuous to aircraft operations
  - Performances similar, or better, to fossil jet fuel in extreme environment
  - Compatibility with tanks, engine, engine and fuel systems

- **Endurance**: yesterday and tomorrow aircrafts operate on the same fuel
  - Life span of an aircraft (therefore the engines) is 40 to 50 years

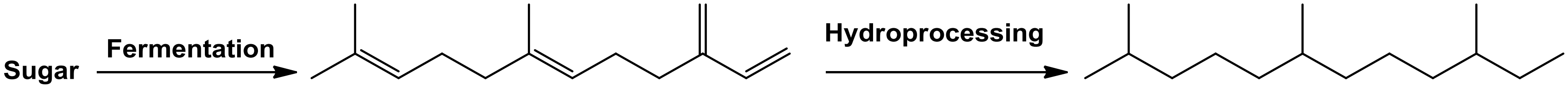
- **Drop-in**: handling, supply and blending of alternative jet fuel should be undistinguishable from jet fuel

- **Price**: renewable jet fuel has to be cost competitive with fossil jet fuel
  - Jet fuels costs correspond to 30 - 55% of airlines' operating costs

**OEMs: Original Equipment Manufacturers*

Airlines, engine and aircraft OEMs* and jet fuel suppliers prefer a renewable, sustainable and drop-in jet fuel available in commercial quantities

# CURRENT STATUS FOR COMMERCIALIZATION: PRODUCTION PROCESS AT SCALE, R&D ON-GOING




Farnesene

Farnesane

- **Fermentation**
  - **Microbe-catalyzed conversion** of sugar: key is the development of a farnesene producing yeast
  - Amyris farnesene plant with a capacity of **up to 50 million liters per year** at target efficiency in Brotas, Brazil
  - Fermentation process demonstrated on three continents: Europe, North America and South America

- **Downstream Processing**
  - Combination of hydro-processing and separation operations
  - Process capabilities on a global basis through Contract Manufacturing Organizations

**Amyris Farnesene plant up and running >2.5 yrs; we were able to address one key aspect for the certification process**

# TOOK A VILLAGE TO RAISE THIS CHILD

- Successful **engines and combustor rig tests**
  - Snecma SaM 146 and P&W 615F on 10% and 20% blends
  - No deviation between blends and reference jet fuel (performance, operability, emissions, post test inspection)

- Validation of the use of farnesane on **Auxiliary Power Unit**
  - Tests performed by Honeywell on 10 and 20% blends
  - Atomization & ignition and APU cold and altitude starting OK

- **Lufthansa** monitored **better emission performances** with farnesane blends **on commercial engine**

- Successful **flight tests with A321 and Etihad B777**
  - Engine fueled with 10% blend performed “normally”


At scale tests confirmed similar performances as with fossil jet fuel



AMYRIS | TOTAL

# COMPLETION OF THE ASTM CERTIFICATION IN JUNE 2014

- Formal ASTM certification is a **2-step ballot process** (>2 months)
  - Research report
  - Revised ASTM D7566 specifications
- **Unanimity is required to pass** (~600 voters are allowed)

Designation: D7566 – 14a

An American National Standard

**Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons[1]**

This standard is issued under the fixed designation D7566; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

**1. Scope***

1.1 This specification covers the manufacture of aviation turbine fuel that consists of conventional and synthetic blending components.

1.2 This specification applies only at the point of batch origination, as follows:

1.2.1 Aviation turbine fuel manufactured, certified, and released to all the requirements of Table 1 of this specification (D7566), meets the requirements of Specification D1655 and shall be regarded as Specification D1655 turbine fuel. Duplicate testing is not necessary; the same data may be used for both D7566 and D1655 compliance. Once the fuel is released to this specification (D7566) the unique requirements of this specification are no longer applicable: any recertification shall be done in accordance with Table 1 of Specification D1655.

1.2.2 Field blending of synthesized paraffinic kerosine (SPK) blendstocks, as described in Annex A1 (FT SPK), Annex A2 (HEFA SPK), or Annex A3 (SIP) with D1655 fuel (which may on the whole or in part have originated as D7566 fuel) shall be considered batch origination in which case all of the requirements of Table 1 of this specification (D7566) apply and shall be evaluated. Short form conformance test programs commonly used to ensure transportation quality are not sufficient. The fuel shall be regarded as D1655 turbine fuel after certification and release as described in 1.2.1.

1.2.3 Once a fuel is redesignated as D1655 aviation turbine fuel, it can be handled in the same fashion as the equivalent refined D1655 aviation turbine fuel.

1.3 This specification defines specific types of aviation turbine fuel that contain synthesized hydrocarbons for civil use in the operation and certification of aircraft and describes fuels found satisfactory for the operation of aircraft and engines. The specification is intended to be used as a standard in describing the quality of aviation turbine fuels and synthetic blending components at the place of manufacture but can be used to describe the quality of aviation turbine fuels for contractual transfer at all points in the distribution system.

1.4 This specification does not define the quality assurance testing and procedures necessary to ensure that fuel in the distribution system continues to comply with this specification after batch certification. Such procedures are defined elsewhere, for example in ICAO 9977, EI/JIG Standard 1530, JIG 1, JIG 2, API 1543, API 1595, and ATA-103.

1.5 This specification does not include all fuels satisfactory for aviation turbine engines. Certain equipment or conditions of use may permit a wider, or require a narrower, range of characteristics than is shown by this specification.

1.6 While aviation turbine fuels defined by Table 1 of this specification can be used in applications other than aviation turbine engines, requirements for such other applications have not been considered in the development of this specification.

1.7 Synthetic blending components, synthetic fuels, and blends of synthetic fuels with conventional petroleum-derived fuels in this specification have been evaluated and approved in accordance with the principles established in Practice D4054.

1.8 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

*1.9 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

**2. Referenced Documents**

2.1 *ASTM Standards:*[2]

D56 Test Method for Flash Point by Tag Closed Cup Tester

D86 Test Method for Distillation of Petroleum Products at

[1] This specification is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.J0.06 on Emerging Turbine Fuels.

Current edition approved June 15, 2014. Published June 2014. Originally approved in 2009. Last previous edition approved in 2014 as D7566 – 14. DOI: 10.1520/D7566-14a.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard



**Commercial flights on 10% blend are allowed since June 2014**



TOTAL

# NEW CHALLENGES: COMMERCIALIZATION AND PRICE REDUCTION

# INDUSTRIAL AND COMMERCIAL OPERATIONS STARTED

- Aviation grade farnesane is produced reliably at commercial scale
  - **Amyris facility in Brotas, Brazil** with a capacity up to 50 million liters per year
  - Successful demonstration of the portability of the process

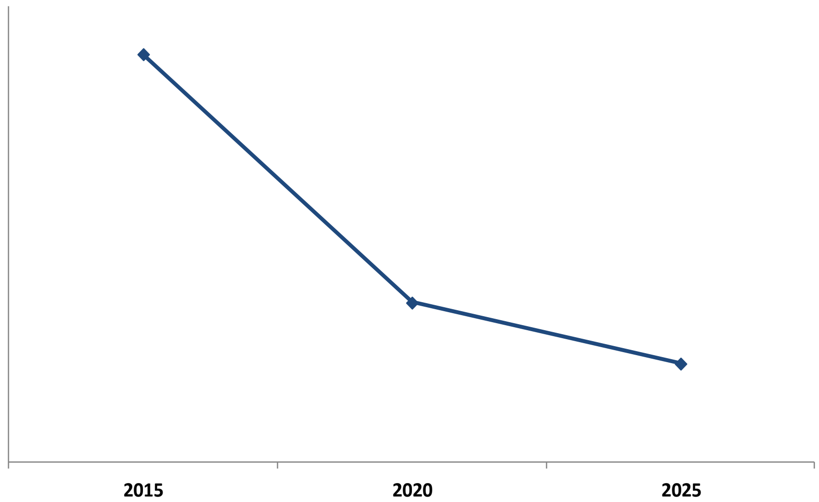

- "Lab'line for the future" with Air France
  - 1 year long program on Toulouse-Paris route with 1 commercial flight / week (A321 equipped with CFM56 engines)
  - Implementation of a **stringent monitoring protocol**
- Compliance with global industry sustainability standards
  - Potential net life cycle GHG emissions: 82% reduction compared to fossil kerosene
  - Farnesene plant received the first RSB (Roundtable on sustainable Biomaterials) certification

Farnesane is available and can be delivered to the wing globally, while respecting aviation industry standards


TOTAL

# TRANSITION FROM DEMONSTRATION TO COMMODITY MARKETS

- Improve **competitiveness** through innovation and quality on the whole value chain




- Efficiency - **Maximum theoretical yield** =
  - *S. cerevisiae* native central metabolism + farnesene synthase
  - Assuming no sugar goes to biomass or to "maintenance"
- Speed - **Maximum theoretical productivity** =
  - Aerobic, oxygen-limited, fed-batch fermentation process
  - $O_2$ delivery

- In the meantime, define **local commercial opportunities** for renewable jet fuel market
  - **Early adopters** wishing to help create a market for reduced GHG emission aviation fuels
  - **Niche markets** in specific favorable environment (regional regulated environment, captive fleets)

Developing Markets while reducing the price to be competitive with other alternatives and also fossil derived Jet Fuel

# HOW ARE WE MAKING THE FUEL READY FOR MARKET?

- Intensive Total sponsored, co-managed R&D program ongoing at Amyris to hit targets that will reduce costs at scale
- Additionally we are looking at partnering on lignocellulosic feedstock valorization technologies to implement when R&D is ready

Caspeta and Nielsen, 2013, Nature Biotech

**Table 1 Mass and energy balances for the metabolic conversion of glucose into target advanced biofuels**

| | | | Physicochemical properties | | Metabolic yields | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Formula | Glucose | $\Delta H_c$[a] | $\rho$[b] | $Y^{s}_{sp}$[c] | $Y^{FBA}_{sp}$[d] | $Y^{FBA}_{pCO2}$[e] | $Y_E$[f] | $Y_{CO2E}$[g] |
| **Biofuels** | | | | | | | | | |
| Heptadecane | $C_{17}H_{36}$ | 4.5 | 47.1 | 0.78 | 0.30 | 0.279 | 2.34 | 0.84 | 49.0 |
| Farnesene | $C_{15}H_{32}$ | 4.5[h]-3.0[i] | 46.4 | 0.84 | 0.25[h] 0.38[i] | 0.276 | 2.26 | 0.82 | 48.0 |
| Fatty alcohol | $C_{16}H_{34}O$ | 4.0 | 43.6 | 0.81 | 0.34 | 0.301 | 1.59 | 0.84 | 36.5 |
| Oleyl ethyl ester | $C_{20}H_{38}O_2$ | 5.0 | 40.5 | 0.79 | 0.34 | 0.319 | 1.92 | 0.83 | 47.0 |
| Isobutanol | $C_4H_{10}O$ | 1.0 | 35.7 | 0.81 | 0.41 | 0.386 | 1.29 | 0.88 | 39.0 |
| Ethanol | $C_2H_6O$ | 0.5 | 28.9 | 0.79 | 0.51 | 0.491 | 1.04 | 0.91 | 36.0 |
| Glucose | $C_6H_{12}O_6$ | – | 15.6 | 1.00 | | | | | |
| **Fossil fuels** | | | | | | | | | |
| Gasoline | $C_4H_{10}$–$C_9H_{12}$ | 43.0 | 0.72–0.77 | | | | | | |
| Diesel | $C_{10}H_{20}$–$C_{15}H_{28}$ | 42.6 | 0.82–0.84 | | | | | | |
| Jet fuel | $C_8H_{18}$–$C_{16}H_{26}$ | 43.4 | 0.76–0.81 | | | | | | |

[a]Heat of combustion in megajoules per kilogram. [b]Density in kilograms per liter. [c]Maximum stoichiometric yield in grams of product per gram of glucose. [d,e]Maximum product (d) and $CO_2$ (e) yields in grams per gram of glucose or product calculated by flux balance analysis (FBA) using the genome-scale metabolic model of *S. cerevisiae*. [f]Energetic yield in megajoules of product per megajoule of glucose based on $Y^{FBA}_{pCO2^e}$. [g]$CO_2$-energy yield in grams of $CO_2$ per megajoule of product based on $Y^{FBA}_{pCO2^e}$. [h]Mevalonate pathway. [i]MEP/DOXP pathway.



TOTAL COMMITTED TO BETTER ENERGY

TOTAL
COMMITTED TO BETTER ENERGY

# THANK YOU