



2nd EU-INDIA CONFERENCE ON ADVANCED BIOFUELS

NEW DELHI
11-13 MARCH 2019

Technologies presented

Edited by Kyriakos Maniatis



Preface

The India-EU Clean Energy and Climate Partnership (CECP) aims to further reinforce the cooperation between the EU and India on climate change and energy implementing the Paris agreement on affordable and clean energy. The partnership brings together all relevant stakeholders European and Indian institutions, EU member states and Indian states, businesses and civil society. The partnership facilitates policy dialogue, brings best practices, business solutions and joint research and innovation and looks at financing models for clean energy and climate change.

The 2nd EU-India Conference on Advanced Biofuels was organised by the Directorate General for Energy of the European Commission and the Ministry of Petroleum and Natural Gas of India under the framework of the India-EU CECP.

The conference aimed at facilitating contacts between industry and technology developers from both the EU and India and eventually establishing cooperation and licencing agreements. Cooperation on research and innovation, which includes biofuels, is an integral part of the EU-India agenda.

This short booklet is a collection of the key technologies and value chains which were presented during the event that was attended by more than 220 participants. The short descriptions of the various value chains have been provided by the technology developers themselves.

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Directorate General for Energy
Unit C2, New Energy Technologies, Innovation & Clean coal

Brussels, 4 April 2019

Disclaimer

This document on "Technologies Presented during the 2nd EU-India Conference on Advanced Biofuels" has been put together by Kyriakos Maniatis based on short descriptions according to a standard template submitted directly by the technology developers who presented at the conference. The submissions have not been altered or edited. These are listed in alphabetical order subject to the type of value chain.

The technologies and value chains listed hereafter are those of the technology developers and industry participants and do not necessarily reflect the official position either of the European Commission or the Ministry of Petroleum and Natural Gas of India; nor they are recommended by the Commission or Ministry of Petroleum and Natural Gas of India.

The European Commission and the Ministry of Petroleum and Natural Gas of India do not guarantee, the accuracy of the status of the technologies included in this report and by no means should they be considered as official recommendations. Neither the European Commission nor the Ministry of Petroleum and Natural Gas of India or any person acting on their behalf may be held responsible for the use which may be made of the information contained herein. The technology developers and industry concerned have offered their views in a personal capacity.

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BIOLOGICAL CONVERSION

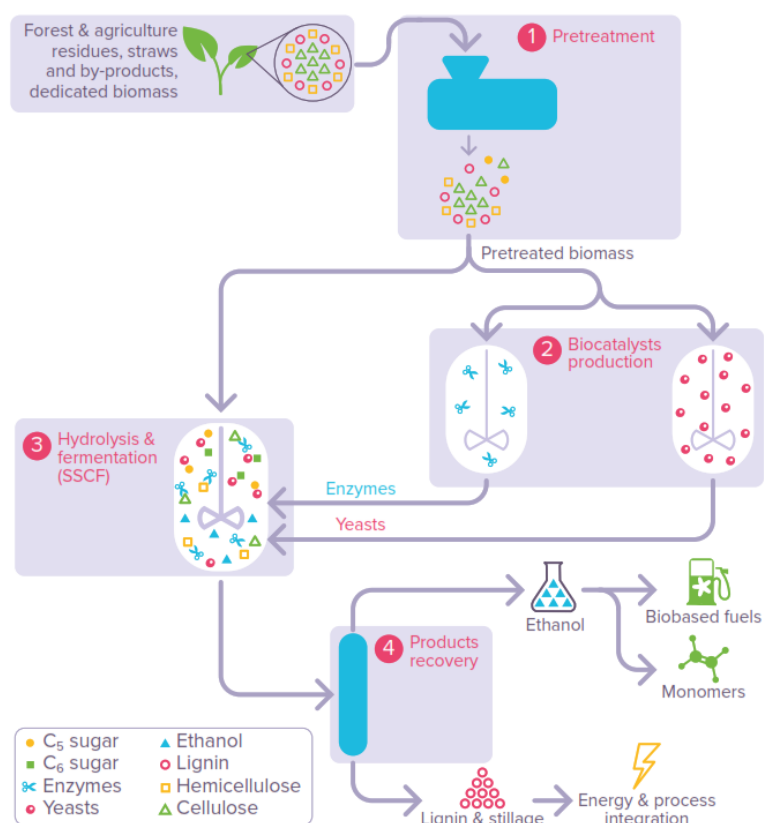
Cellulosic Ethanol

Biogas- Biomethane

FuturoI™

FuturoI™ technology addresses today's challenges of sustainability and lower greenhouse gas emissions through the production of 2nd generation (2G) bio-ethanol from various biomasses suitable for fuel and chemical applications alike.

Lignocellulosic ethanol production through FuturoI™ technology is a simple and integrated 4-step process:



- 1. Pretreatment**
 - Wide range of biomasses
 - Standardized substrate
 - Low moisture, high digestibility
 - High C₅ sugars yield
- 2. On-site biocatalysts production**
 - Tailor-made enzymes/yeasts
 - High resistance to inhibitors
 - Fully adapted to substrate
 - Production cost reduction
- 3. Hydrolysis and fermentation**
 - "One-pot" SSCF
 - CAPEX/OPEX minimization
 - Full C₅/C₆ sugars conversion
 - High ethanol yield
- 4. Products recovery**
 - Energy/process integration with the valorisation of lignin/stillage

Demonstration scale

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|---------------------------------|---------------|-----------------------------|---------------|----------------------------------|----------------------|----------------------|------------|--------------------|
| Biomass Pretreatment Industrial | Demonstration | Testing campaigns completed | 2016 | Several including straw and wood | 100 tonnes/day (dry) | Pretreated substrate | N/A | N/A |

Find hereafter a picture of our Biomass Pretreatment Industrial Demonstration plant integrated in Tereos site (Bucy-Le-Long, France):

**Established in India**

Axens has been a market leader for technology licensing in India since the 1970's with more than 120 licensed units. After the recent takeover of Heurtey Petrochemicals, we offer a complete range of solutions including technologies, equipment, furnaces, modular units, catalysts and services for Refining, Petrochemicals, Renewables, Gas & Water. With 2 offices in Delhi and Mumbai and 1 manufacturing yard at Por, Baroda (Gujarat), Axens responds in a agile way to clients new requirements and market changes.

Contact:

SAHA Siddhartha - Country Head - Sales & Marketing, Sales PCA

Siddhartha.SAHA@axens.net



BHARAT PETROLEUM CORPORATION

Technology developed: Lignocellulosic Second Generation (2G) Ethanol Technology

Bharat Petroleum Corporation Ltd. Proposes to set up a Lignocellulosic Second Generation (2G) Ethanol Bio-refinery at Bina, Sagar District (Madhya Pradesh) in India based on technology provided by DBT-ICT, Mumbai. The Biorefinery will have a capacity to produce 100 kilo litres of Ethanol per day. About 2 Lakh tonnes per annum of Soya Stalk/ Wheat Straw will be used as feedstock in the plant.

UNDER CONSTRUCTION

Commercial plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|------------|------------|---|---------------|--------------------------|--------------------|---------------------------------|-----------------------------|--------------------|
| BINA | Commercial | Discussions with Licensor (DBT-ICT) in progress | 2023 | Soya Stalk / Wheat Straw | 430 tonnes /day | 100 kilo litres per day Ethanol | 75 tons/day CO ₂ | - |

Bharat Petroleum Corporation Limited (BPCL) is an Oil Marketing Company (OMC) under the Ministry of Petroleum & Natural Gas (MoP&NG), Government of India, and has its Oil Refineries at Mumbai & Kochi. BPCL proposes to set up total three Lignocellulosic Second Generation (2G) Ethanol Bio-refineries in the states of Odisha, Madhya Pradesh and Maharashtra in India using biomass like Rice straw, Wheat straw, Soya stalk etc.

Contact: Mr. M.S Patke, ED(HSSE & Advanced Liquid Biofuels), patkems@bharatpetroleum.in



BHARAT PETROLEUM CORPORATION

Technology developed: Lignocellulosic Second Generation (2G) Ethanol Technology

Bharat Petroleum Corporation Ltd. is setting up a Lignocellulosic Second Generation (2G) Ethanol Bio-refinery at Bargarh District (Odisha) in India based on technology provided by M/s Praj Industries Ltd., Pune, Maharashtra, India. The Biorefinery will have a capacity to produce 100 kilo litres of Ethanol per day. About 2 Lakh tonnes per annum of Rice straw will be used as feedstock in the plant.

UNDER CONSTRUCTION

Commercial plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|------------|------------|--------------------|---------------|--------------|--------------------|---------------------------------|-----------------------------|--------------------|
| BARGARH | Commercial | Under Construction | 2021 | Rice Straw | 480 tonnes /day | 100 kilo litres per day Ethanol | 75 tons/day CO ₂ | - |

Established in India

Bharat Petroleum Corporation Limited (BPCL) is an Oil Marketing Company (OMC) under the Ministry of Petroleum & Natural Gas (MoP&NG), Government of India, and has its Oil Refineries at Mumbai & Kochi. BPCL proposes to set up total three Lignocellulosic Second Generation (2G) Ethanol Bio-refineries in the states of Odisha, Madhya Pradesh and Maharashtra in India using biomass like Rice straw, Wheat straw, Soya stalk etc.

Contact: Mr. M.S Patke, ED(HSSE & Advanced Liquid Biofuels), patkems@bharatpetroleum.in

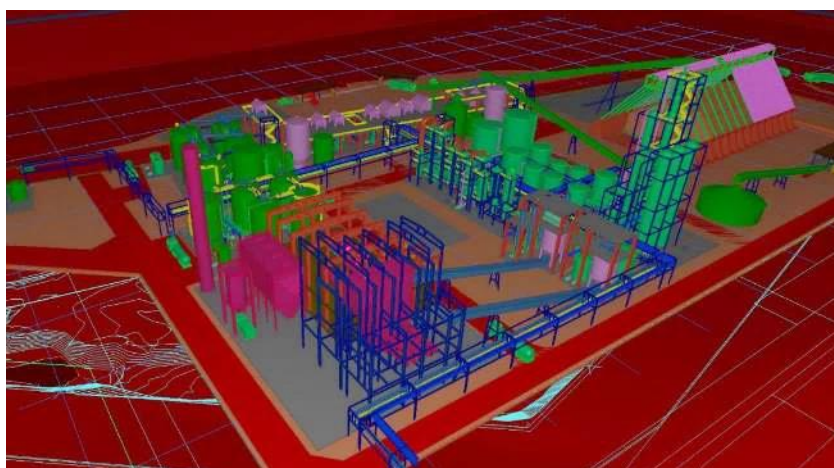
formicobio™ - 3G technology for the production of cellulosic ethanol

formicobio™ process technology is based on selective fractionation of cellulosic biomasses into main components using biosolvent. Biosolvent and water used in the process are recovered and re-used, and biorefining co-produces excess green power. The technology enables profitable and sustainable biorefining of various biomasses such as straws, sugarcane bagasse, bamboo, and woody biomasses. Compared to typical 2G ethanol technologies, **formicobio™** offers higher revenues and lower operating costs. Generated acetic acid and furfural are recovered as valuable co-products instead of them treating as waste. Pure cellulose fraction enables reduced enzyme consumption and simple fermentation using conventional yeasts.

First commercial biorefinery based on the formicobio™ technology

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product |
|-------------------|------------|--------------------|---------------|--------------|--------------------|-------------------|--|
| ABRPL biorefinery | Commercial | Under Construction | 2021 | Bamboo | 300000 t/a (dry) | 50000 t/a ethanol | 30000 t/a platform chemicals + 12 MW green power |

Biorefinery based on the **formicobio™** technology under construction in Numaligarh, Assam, India



Established in India

Chempolis India Pvt, full subsidiary of Chempolis Oy, operates in India focusing on the business development for biorefinery projects, which would be converting local lignocellulosic biomasses for cellulosic sugars, advanced biofuels, biochemicals, fibres and green power. Chempolis Oy is licensor, investor and shareholder of ABRPL biorefinery company by 22 % shareholding.

Contact: Pasi Rousu, Senior Advisor, Chempolis Oy, Director Chempolis India Pvt.
pasi.rousu@chempolis.com

Clariant

Technology developed

CLARIANT's innovative sunliquid® technology for the production of cellulosic ethanol was developed over the last decade and offers an innovative technical approach. The fully integrated process converts agricultural residues such as cereal straw or corn stover to cellulosic ethanol via mechanical and thermal pretreatment, enzymatic hydrolysis with feedstock and process specific enzymes, simultaneous C5 and C6 fermentation and energy efficient ethanol separation. Key technology process elements: chemical free pre-treatment eliminating acid and alkali consumption, lowering production and investment costs & minimizing environmental, health and safety risks - fully process integrated enzyme production & yeast production, feedstock optimised, whereby integration takes advantage of small amounts of hydrolysate produced on-site (cheaper vs conventional sugar sources) - early separation of lignin (>60% dry, used for burning) & vinasse (used as fertilizer, biogas or fuel use) as individual streams to improve quality & exploitation value (also providing access to sunliquid® sugar hydrolysate as a promising platform feedstock for biodiesel, bio-based chemicals & bio-plastics) thanks to their superior quality derived from the chemical free pre-treatment. CLARIANT has developed these process steps combining its extensive biotechnological expertise in enzyme and strain development with detailed process developments to improve the cost-efficiency and sustainability (lower CAPEX, lower production costs, and decreased energy use) of the lignocellulosic ethanol production, more information: www.sunliquid.com

Demonstration scale/Commercial plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|---------------------|---|----------------------------------|---------------|---|----------------------|---------------------|---|-----------------------|
| sunliquid– Romania | Commercial | Under Construction | 2020 | Wheat straw, barley straw, corn stover | 750-800 t/day (dry)* | 150 t/day (ethanol) | Vinasse as fertilizer or energy source, Lignin as energy source | - |
| Enviral – Slovakia | Commercial (sunliquid technology license) | Construction to commence 2020/21 | 2021/22 | Local agricultural residues | Customer information | 150 t/day (ethanol) | Customer information | - |
| sunliquid - Germany | Pre-commercial | Operation | 2012 | eg. wheat/barley/rice straw, corn stover, miscanthus, sugarcane bagasse & tops&leaves | 12-16 t/d (dry)* | up to 3 t/day | Vinasse as fertilizer or energy source, Lignin | Since 2012 continuous |

* depending on feedstock as plant operates with multiple feedstock



precommercial plant in Germany



sunliquid plant in Romania

Established in India

Clariant in India has its HQ in Mumbai with 10 manufacturing facilities spread across Vashere & Roha in Maharashtra; Cuddalore in Tamil Nadu; Rania & Kalol in Gujarat; Nagda in Madhya Pradesh; Bonthapally in Telangana and Edayar in Kerala & 6 sales offices. Key areas of business – BU Pigments, Masterbatches, Additives, Industrial & Consumer Specialties, Functional Minerals & Catalysts. Number of total FTE's 1355. A dedicated local team for biofuels has aggressively initiated business development activities in India.

Contact: Markus Rarbach, Head of Business Line Biofuels&Derivatives sunliquid@clariant.com

DBT-ICT Centre for Energy Biosciences



Institute of Chemical Technology, Mumbai



The DBT-ICT 2G-Ethanol/2G-Sugar Technology

The DBT-ICT 2G-Ethanol/2G Sugar Technology is a feed-stock agnostic process that fractionates any biomass feedstock (hard wood chips, cotton stalk, soft bagasse, rice straw, etc) into separate streams of glucose (C6), xylose (C5) and lignin. The C6 and C5 sugars produced as intermediates can be co-fermented to produce ethanol, or can be converted to other chemicals, and ash-free lignin can be used directly as boiler fuel or via biogas for steam/power generation. Major and distinct features of the technology are: (a) through and through continuous flow processing from biomass size reduction to fermentation; (b) low chemical, enzyme and water consumption through recycle & reuse; (c) Low overall processing time of 18 h from feed to alcohol; (d) zero liquid discharge; and (e) possibility of using C6 and C5 sugar intermediates for making other products. The compact plant design has unique features such as advanced reactor design and separation technologies with slurry-flow rapid rate operations. The technology offers optimization on CAPEX/OPEX as well as on a range of chemicals that can be produced from 2G-sugars using smart chemical/biological routes. The technology can be easily used at scales from 100 to 500 ton biomass/day.

Status: Demonstration scale; 2 Commercial plants being built

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|---------------------------------------|----------|--------------------------------|---------------|---|--------------------|-------------------------------|---|---|
| 2G-Ethanol plant at India Glycols Ltd | D | Operating | March 2016 | Any feedstock | 10 ton/day | Ethanol (750,000 L per annum) | Lignin | 4000h |
| HPCL, Bhatinda plant, Punjab | C | Under Construction | Expected 2020 | Proposed for Rice straw, cotton stalk | 450 ton/day | Ethanol (100 KL) | Silica, Food grade carbon dioxide, inorganic mineral fertilizer |  |
| BPCL, Bina, Madhya Pradesh | C | In process for finalizing BEDP | Expected 2021 | Proposed plant for wheat straw and soya | 450 ton/day | Ethanol (100KL per day) | Food grade carbon dioxide, inorganic mineral fertilizer |  |



The technology has been validated and demonstrated at India Glycols Limited, Kashipur, Uttarakhand, India.

Capacity: 10 ton/day,

Product: 2G-Ethanol, 2G-Sugar, lignin

Established in India

To achieve the 10% blending target set up by the Govt. Of India, several OMC (Oil Marketing Companies) are setting up ethanol biorefinery plants in India. Front End Engineering has been done for the plant being erected by Hindustan Petroleum at Bathinda, Punjab, India and the unit is expected to be operational by

end of 2020. Basic Engineering and Design Package (BEDP) is being finalized for the plant in Bina, Madhya Pradesh, India by Bharat Petroleum Corporation Ltd.

The DBT-ICT Centre for Energy Biosciences is India's first dedicated state-of-the-art centre mandated to develop technologies for production of renewable fuel and chemicals. In addition to ethanol, the Centre with its vibrant talent combining expertise in modern biology & chemistry with engineering sciences, also works on developing technologies for methane, organic acids, and biomaterials like PLA, bioPET, butadiene among many others in the field of food and feed. Demo scale biorefineries manufacturing products like butanol, lactic acid, propanoic acid, bio-vanillin, bio-xylitol and food grade protein have been built or are being built. The Centre also has one of the most advanced algal research facilities and algal biorefineries are under construction.

Contact: Prof. Arvind M. Lali

arvindmlali@gmail.com; am.lali@ictmumbai.edu.in

DBT-ICT Centre for Energy Biosciences

Institute of Chemical Technology, Mumbai



The DBT-ICT Compressed Biogas Technology

The traditional biogas production from solid substrates like biomass and municipal solid waste (MSW) suffers from two major limitations for scale-up: (1) Incomplete conversion to product biogas (typically 50-60%); and (2) slow reaction rates with HRTs of 20-150 days. The DBT-ICT Biogas technology overcomes both these limitations and achieves biogas production with 90% carbon conversion in quick time of 1-3 days. The technology involves catalytic conversion of any and all unsegregated wet and dry organic waste (biomass, municipal solid wastes, municipal sewage, industrial effluents/sludge, cattle dung, etc.) into liquid hydrolysate that is free from sulphur, nitrogen and ash. This hydrolysate oil when subjected to DBT-ICT Rapid-AD Technology (AD-anaerobic digestion) gives rapid biogas generation with high conversion efficiency in uniquely designed biodigesters in quick time thereby requiring much smaller digesters. The overall technology is clean, zero-discharge, compact and efficient that requires low land footprint. The technology is shown to be revenue positive for all wastes.

Status: Demonstration scale

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|----------------------------------|----------|--------------------|---------------|---------------|--------------------|---------|-------------------------|--------------------|
| BPCL residential colony, Mumbai | D | Under construction | 2019 | MSW | 1 ton/day | Methane | Clean water, Fertilizer | - |
| Barapullah Drain, Delhi | D | Under construction | 2019 | Sewage Sludge | 1 MLD | Methane | Clean water, Fertilizer | - |
| East Delhi Municipal Corporation | C | Under design | 2020 | MSW | 30 ton/day | Methane | Clean water, Fertilizer | - |

Established in India

The demonstration of the technology decided scale will lead to multiple plants with widespread private participation. The demonstration plants for processing 1 to 30 ton/day bio-waste under construction at Bharat Petroleum Corporation Ltd. Residential colony, Mumbai and in East Delhi Waste Yard will both be operational by end of 2019 and early 2020, respectively.

Contact: Prof. Arvind M. Lali

arvindmlali@gmail.com; and am.lali@ictmumbai.edu.in

Indian Oil Corporation



Technology developed : Compressed Bio Gas (CBG)

Biomass and waste sources like agricultural residue, cattle dung, poultry manure, other organic residues & waste materials etc. produce Biogas through the process of anaerobic decomposition. The Biogas is then purified and compressed to form Compressed Bio Gas (CBG or Bio-methane), which has Methane (CH₄) content of more than 90%. CBG has calorific value and other properties very similar to Natural Gas (CNG) and hence can be utilized as a green, renewable automotive fuel. The Sustainable Alternative Towards Affordable Transportation (SATAT) Scheme was launched in India on 1.10.2018. The scheme envisages production and marketing of CBG from 5000 plants by March 2023. The estimated 5000 plants are expected to produce 15 million tons of CBG. Under the SATAT scheme, IndianOil has invited Expression of Interest (EOI) from CBG producers to produce & supply CBG at a delivered price of Rs. 46 per kg. For details on the scheme, <https://www.iocl.com/Satat.aspx> may be referred to.

IndianOil has developed an innovative two stage anaerobic digestion technology to significantly increase Bio-gas production. IndianOil has also developed an enviro-tolerant inoculant, which produces higher biogas with high methane and reduced CO₂ content. The combined process has resulted in Biogas yield of 1.5-2 times over conventional process having methane content of 75-80% in raw Biogas.

Status: Commercial plant

Under the SATAT scheme, IndianOil has released Letter of Intent to successful parties who had applied for the EOI, to procure CBG from a number of Plants across India. The CBG producers include indigenous and global Parties.

IOT Biogas Pvt. Ltd. is a subsidiary of a JV of IndianOil, which operates a Bio-gas Plant at Namakkal, Tamil Nadu. The inoculums developed by IndianOil has been used in the Plant.



| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product |
|----------------------------------|------------|------------------------|---------------|--|---------------------------------------|--|------------|
| IOT Biogas, Namakkal, Tamil Nadu | Commercial | Operational since 2012 | 2012 | Press mud, Chicken litter, cattle dung, etc. | Designed capacity 290 TPD mixed waste | Presently Biogas (24000 m ³ /day) used to produce electricity. Purification & compression units being set up to produce CBG | Manure |

Indian Oil Corporation Ltd.

IndianOil is an integrated energy major and India's largest commercial enterprise, ranking 137th in Fortune Global 500 list of companies. IndianOil is involved across the value chain of oil & gas including exploration, production, refining, petrochemicals, pipelines, distribution & marketing with advanced R&D facilities. IndianOil has also ventured into alternate energy including Biofuels, wind, solar, electric mobility, etc. The total employee strength of IndianOil is over 33,000 with a network of over 47,800 customer touch-points.

Contact: Subodh Kumar, Executive Director (Alternate Energy & Sustainable Development)

E-mail : ksubodh@indianoil.in

Leaf – Lesaffre Advanced Fermentation



CelluX™ 4

CelluX™ is a genetically modified strain of *Saccharomyces cerevisiae* developed for the cellulosic ethanol industry. CelluX™ 4 has a strong tolerance to inhibitors. This xylose fermenting yeast strain demonstrates the ability to resist stresses and maintains higher cell viability especially during fermentations of hydrolyzed cellulosic material. CelluX™ 4 is available in dry format which allows 24 months shelf life from production date under recommended storage conditions.

Status: CelluX™ 4 is available at commercial scale and produced in our dedicated GMO yeast dryer in Dothan, Alabama (USA).

| Plant name | Type D/C | Status | Start-up year |
|-------------------------------|------------|-----------|---------------|
| Lesaffre Dothan, Alabama, USA | Commercial | Operating | 2017 |



Advanced fermentation services

Leaf offer distinctive competencies and capabilities to our partners at each step of their projects from yeast strain engineering, process scale-up and optimization through to industrial scale manufacturing of yeast biomass.



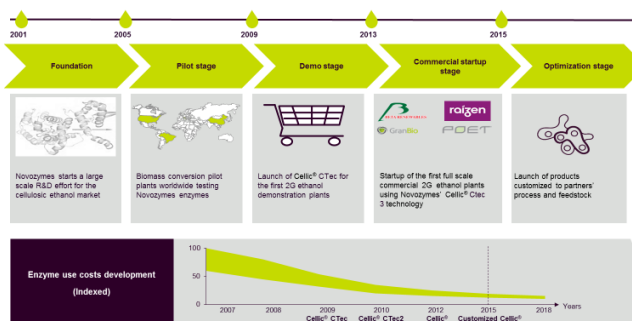
Contact: Didier Masy, General Manager, d.masy@leaf.lesaffre.com

Novozymes

Technology developed

Novozymes has been a pioneer in the development of the 2G industry globally. Cellulosic ethanol production requires enzymes to convert the biomass to free sugars in the enzymatic hydrolysis process. Novozymes Cellic® product line helps secure the lowest cost of producing ethanol by unlocking new ways to optimize a plant's conversion process. Novozymes has partnered widely with leading industry players, and together worked with the Cellic® product family to optimize the cellulosic ethanol production process.

Two decades of cellulosic ethanol development



Having research and innovation at the core, and a supply chain unrivalled in scale and scope, Novozymes is able to guarantee most reliable and consistent enzyme supply at most competitive prices.

Commercial plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|-------------|------------|-------------|---------------|------------------------|--------------------|----------------------------|-----------------------------------|--------------------|
| Crescentino | Commercial | Operational | 2013 | Wheat straw/Rice straw | 200,000 tonnes/yr | 40,000 tonnes/yr (ethanol) | Green electricity (13MW capacity) | n/a |



Crescentino, Province of Vercelli, Italy (IEA report)

Established in India

Novozymes has been present in India for more than 3 decades with its South Asia headquarters in Bangalore. With more than 650 employees in India, Novozymes caters to a wide variety of sectors including household care, agriculture, bioenergy, animal health & nutrition, food & beverage, textiles, pulp & paper, leather etc. To cater to the growing India and South-East Asia markets, Novozymes has recently invested around DKK 300 million to build a new production and supply chain facility near Mumbai.

Contact: Thomas Schrøder, VP, Biorefining Commercial, TSHD@novozymes.com

(Renewable Energy Consortium for R&D)

Biomethane and Biogas

On biogas, RE-CORD (www.re-cord.org) is partner with BTS (<http://www.bts-biogas.com/en/>), the leading Italian company on biogas and biomethane. BTS, headquartered in Brunico, IT, employs more than 100 people, developed over 220 plants worldwide for a total capacity exceeding 185 MW, and holds 26 patents on the sector. Biomethane is the new business for biogas producers, and BTS plays a key role in that area. The proposed systems are modular, designed to meet client's needs. Various pretreatments are available, among which BIOaccelerators (impact reactor, biomass defibrator), acquAEXTRUSION, fibreCRACK (SE), TRANSFORMER (shredder). Also 4 different upgrading technologies (membrane, chemical scrubbing, water scrubbing PSA) and post-treatment technologies (BIOdry, NITROstripp, BIOpellet, COMPOfert, NPKlean) are available. A large variety of feedstocks can be fed to the plants, as agricultural and industrial byproducts, energy crops, etc. Innovative high TRL-solutions are under study by BTS in collaboration with RE-CORD, as co-composting of biochar and digestate, Integration of slow pyrolysis and anaerobic digestion (mass and energy), and Pretreatment of lignocellulosic biomass.



Status of technology: Full commercial-scale solutions. Large number of references are available on request (see also <http://www.bts-biogas.com/en/plants/>).



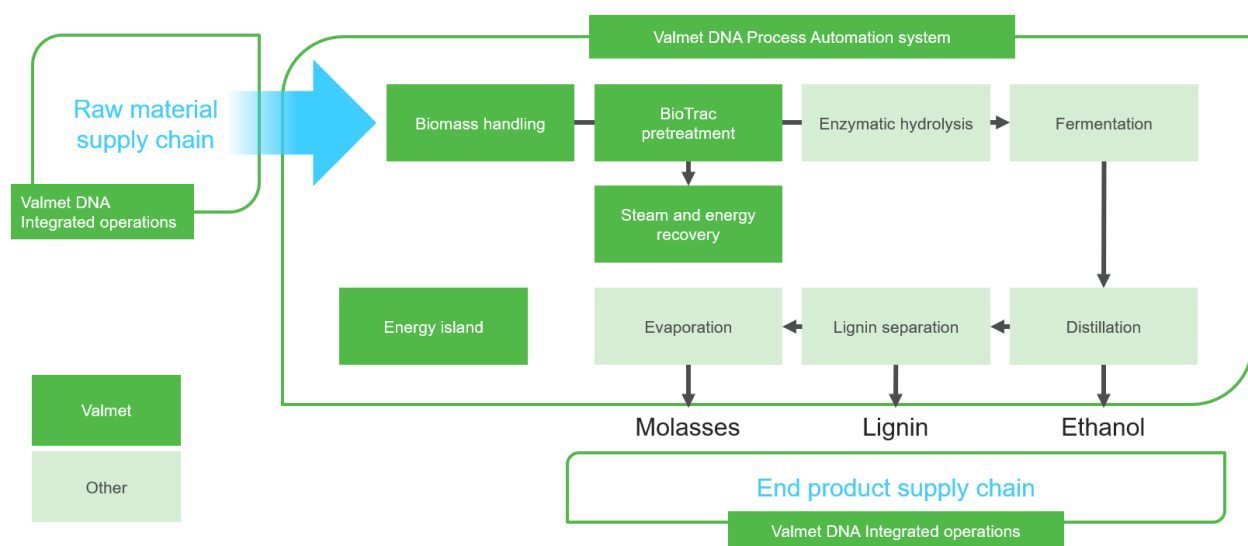
Established in India - Not yet established in India, as of March 2019.

Contact: David Chiaramonti, RE-CORD President, david.chiaramonti@re-cord.org

BioTrac Pretreatment

Valmet is in the field of cellulosic sugar/ethanol/biochemical a technology provider and not an end to end provider (please see below schematic). Special attention has been given to the Pretreatment area, marketed under the name BioTarc. The BioTrac is developed based on decades of experience in design and supply of systems to process biomass into various renewable products e.g. pulp and fibreboard. Based on this foundation, the BioTrac has been further developed through the experiences gained in the >20 deliveries done to date. The deliveries ranges from, pilot, demo and commercial scale. From 2010, 12 systems have been sold.

Valmet's Potential Offering



Valmet has a wide range of offering primarily related to pulp, paper and energy and is also offering in addition to above solutions related to Black Pellets/Biocoal, Bio-oil, Gasification and lignin separation in pulping (Lignoboost). For more information visit www.valmet.com.

References

Demonstration scale/Commercial plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|------------|----------|--------------------|---------------|--------------|---------------------|---------------|------------|--------------------|
| Clariant | C | Under Construction | 2020 | Straw | 820 tonnes/d (dry) | 2G ethanol | - | - |
| FICAP | C | Under Construction | 2020 | Wood | 360 tonnes/d (dry) | Black Pellets | - | - |
| Confid. | C | Under Construction | 2020 | Straw | 1000 tonnes/d (dry) | 2G ethanol | - | - |
| Confid. | D | In operation | 2016 | Straw/Wood | 70 tonnes/d (dry) | 2G ethanol | Confid. | Confid. |
| Confid. | C | In operation | 2016 | Straw | 600 tonnes/d (dry) | 2G ethanol | Confid. | Confid. |

| | | | | | | | | |
|----------|---|--------------|------|-------|-------------------|------------|---------|---------|
| Clariant | D | In operation | 2012 | Straw | 10 tonnes/d (dry) | 2G ethanol | Confid. | Confid. |
|----------|---|--------------|------|-------|-------------------|------------|---------|---------|



Established in India

About 300 employees working in India within sales, engineering and service. Locations, Gurgaon, Vadodara, Chennai and Mumbai. Has a long history and delivered several projects to pulp, paper and energy business.

Contact: Mattias Erixon, Manager Sales, mattias.erixon@valmet.com

Versalis



versalis

Technology developed: PROESA[®]

PROESA[®] technology by Versalis is based on a chemical-free pretreatment of cellulosic feedstock executed with saturated steam followed by viscosity reduction and enzymatic hydrolysis that prepare 2G sugars for fermentation to bioethanol. The major by-product is the lignin, that can be utilized as solid fuel into biomass boilers to produce electricity and steam: in the future, further application of the lignin as intermediate towards other valuable products is foreseen. The technology accepts a wide variety of biomasses as feedstock such as wheat and rice straw, corn stover, sugar cane bagasse and tops and leaves, dedicated non-food energy crops (i.e. Napier Grass, Miscanthus), hardwood. Using a chemical-free pre-treatment it is possible to avoid expensive construction materials and to minimize the formation of inhibitory compounds, therefore maximizing the bio-catalysts activity. The state-of-the-art design of enzymatic hydrolysis facilitates an easy scale-up and effective pH and temperature control. The yeast used in the fermentation stage is capable of fermenting both C6 and C5 sugars and it is propagated on site. The PROESA[®] technology has been applied in the world-first commercial-scale 2G ethanol plant in Crescentino (Italy), in operation since 2014: the plant includes a power plant operated at 13 MWe, a biogas production unit and a WWT unit designed for total water recirculation. Leveraging on the experience developed in Crescentino, Versalis is licensing the technology worldwide, supporting the customers during all steps of project development.

Status

Commercial plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|-------------|------------|---|---------------|-----------------|--------------------|-----------------------------|---------------------------------|--------------------|
| Crescentino | Commercial | Operational (currently under maintenance) | 2013 | Straw, hardwood | -- | Fuel grad Ethanol (22 ktpy) | Lignin Biogas Electricity | |



2G EtOH plant in Crescentino (Italy)

Established in India

Versalis Pacific (India) Pte Ltd has been established in 2013 and is located in Mumbai. Main focus of the Indian subsidiary is in the traditional business lines of Versalis (intermediate, styrenics, elastomers, polyethylene). The licensing activity in the area of cellulosic ethanol and green chemistry is followed directly by Versalis HQ in S.Donato Milanese (Italy) and supported locally by our commercial agent (Unison Consulting).

Contact:

Pierluigi Picciotti, Versalis S.p.a., Licensing Expert Green Chemistry,
pierluigi.picciotti@versalis.eni.com

Abhijeet Shinde, Versalis Pacific (India) Pte. Ltd, Sales Manager abhijeet.shinde@versalis.eni.com

Vinod Unni, Unison Consulting, New Delhi, President vinod.unni@consultunison.com

Demonstration plant: Renasci NV



Technology for the conversion of the organic fraction of municipal solid waste into bioethanol, isobutanol and Glycerol Tertiary Butyl Ether (GTBE)

The company Renasci has developed a technology called 'Smart Chain Processing' for the recycling of all fractions in municipal solid waste (MSW). It will also include a process for the conversion of the organic fraction (OF), which mainly consists of paper and cardboard, into ethanol, isobutanol and GTBE.

The enzymatic hydrolysis and yeast fermentation processes are developed by VIB. A technology for the conversion of the MSW-OF into ethanol has been established. The technology for the conversion of the MSW-OF into isobutanol, including construction of the 2G isobutanol yeast strain, is under development.

The isobutanol produced will be converted by chemical catalysis into isobutene, which will then be coupled to glycerol, derived from the production of biodiesel using animal fat or other substrates, to produce GTBE. This is a valuable fuel additive for both gasoline and diesel, that improves engine performance and cuts harmful exhaust emissions.

MSW-OF → enzymatic hydrolysis → fermentable sugars → fermentation with 2G yeast → ethanol

MSW-OF → enzymatic hydrolysis → fermentable sugars → fermentation with engineered 2G yeast → isobutanol → chemical conversion → isobutene → chemical conversion + glycerol (derived from biodiesel production) → GTBE

Process under development/demo plant under construction

Demonstration scale

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|-----------------|---------------|--------------------|---------------|--|--------------------|---------------------------|------------|--------------------|
| Ostend, Belgium | Demonstration | Under Construction | 2020 | Organic fraction of MSW (paper/card board) | 12,000 tonnes/year | Ethanol, isobutanol, GTBE | Residue | - |



Ostend, Belgium, 12,000 tonnes/year, MSW-organic fraction, ethanol, isobutanol, GTBE

Contact: Johan Thevelein, professor, johan.thevelein@kuleuven.vib.be

THERMOCHEMICAL CONVERSION

Waste to Mixed Alcohol

Hydrotreated Oils

Mixed Alcohols to Jet Fuel

Technology developed : Waste to Mixed Alcohol

Technology developed in two parts

- A. **Waste to Syngas** – Plasma Enhanced Gasification System (PEGS®) Technology owned by Enersol technologies Inc, Virginia USA, originally supported by US Dept of Defence and Dep't of Energy. All patents held by the company. The design is modular in nature
- B. **Syngas to mixed alcohols – Catalytic Alcohol Synthesis System (CASS)**. Technology and patents owned by Western Research Institute, Wyoming and technology development is part funded by US DoE The mixed alcohol can then be separated into Ethanol, Methanol Propanol having industrial grade specifications, in case customer so desires. The mixed alcohol produced is in fact can be directly blended and is a better blend than ethanol.

Feedstock; Municipal solid waste, plastics, agri-waste / biomass (woodchips, rice straw, cotton, maize, walnut shell, pine nut etc), hazardous waste, Petcoke, tyres, textiles, bio-medical waste, etc. Individually and in mixed manner.

A. Plasma Enhanced Gasification System (PEGS®)

Process; Staged Plasma Gasification. Emission is better than US EPA standards

Bottom residue; slag, non-toxic

Syngas from PEGS® is without any tars and is further cleaned in the Gas cleaning system that is suitable for conversion into Ethanol/Methanol or for producing electricity through a gas engine. Waste having moisture up to 45 – 55% level is acceptable. Gasifier is modular design. Expansion in 50, 100 , 250 TPD possible

B. Catalytic Alcohol Synthesis System (CASS)

Process - Conversion of Syngas into Mixed Alcohols through a catalyst process. The catalyst for the process developed by Western Research Institute (WRI), Wyoming, USA, and patents held by WRI. Mixed alcohol stream can be separated by distillation into ethanol, methanol and propanol if required. Reaction being exothermic, there is surplus electricity available for export.

Technology developed at 2 barrels per day level (Syngas volume equivalent to approx. 4 – 5 TPD of RDF derived from MSW).

Commercialisation: Both Technologies ready for commercialisation in India.

Commercial bids submitted in US for waste to mixed alcohol

Technology Advantages:

- Process is feed agnostic
- Variety of feed individually & in mixed manner acceptable
- Water required only for cooling and waste steam generation. No process Water
- Environmentally safe, nothing to Landfill, Residue in Slag form which is non-toxic
- Capex & Opex; At 100 kl per day Ethanol, capex and opex lower than the Biological route

Current Status:

PEGS® Technology (Waste to Syngas) developed by Enersol Technologies USA at 5 TPD (mobile) / 10TPD (fixed Installation) level and engineering carried out for 150 TPD facilities, CASS Technology (Syngas to Mixed alcohol) developed by WRI , USA at 2 barrels per day level (Syngas volume equivalent to approx. 4 – 5 TPD of RDF derived from MSW).

Discussions are at advance stage for a project of 100 kl per day Ethanol capacity. From date of finalisation project can be implemented within 24 months.

Contact Person:

Radhakrishnan Srinivasan

Chairman & Managing Director

Alchemy Enersol International Pvt Ltd

A 104, Logix Technova, Sector 132

Noida – 201304, Uttar Pradesh, India

E-mail: radkrish@enersolindia.com

Ph nos: +91 120 4253691; +91 120 4277747; +91 98711 83886, +91 93151 73168

Fax: +91 120 4573356

www.enersolindia.com

Demo plants:**Plasma Enhanced Gasification System (PEGS®), Enersol Technologies Virginia USA****Catalytic Alcohol Synthesis Process (CASS), WRI, Wyoming, USA**

AXENS



Vegan®

Vegan® technology is a flexible solution for producing renewable diesel and jet through the hydrotreatment of a wide range of lipids. This technology allows producers to effectively address today's environmental concerns and secure energy diversification with "drop-in" premium quality products.

Vegan® technology is based on catalysts developed, manufactured and provided by Axens.

Axens notable know-how in lipids processing, middle distillates hydrotreatment and hydrocracking/hydro-isomerization - associated with extensive pilot testing and accurate predictive models - ensures Vegan® technology the flexibility to convert all vegetable oils and animal fats, including used cooking oil (UCO) and algal oil.

Vegan® technology is a simple 2-step process producing renewable diesel and jet with excellent properties.

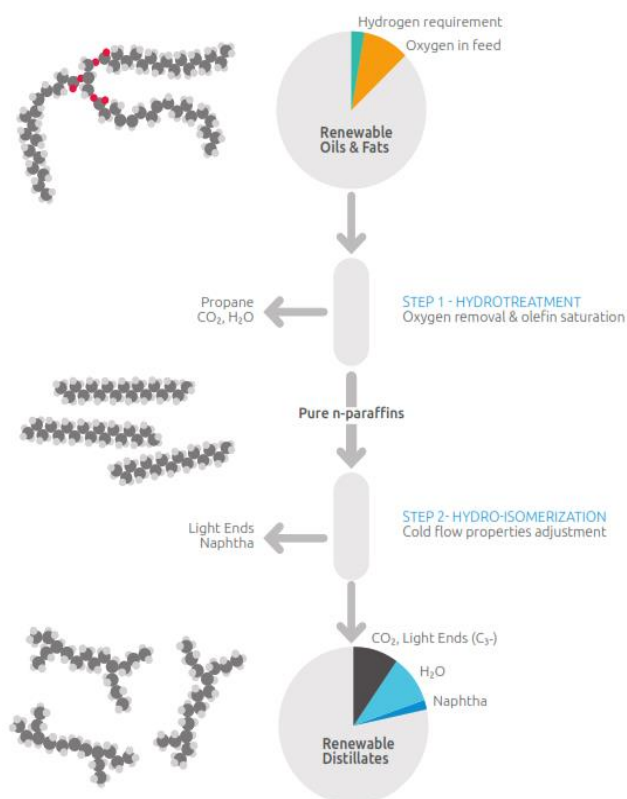
| PROPERTY | UNIT FEED | SUMMER DIESEL | WINTER DIESEL | JET FUEL |
|-----------------------------|--------------|------------------|------------------|-------------|
| FREEZING PT/CFPP (°C) | 30 | 0 | -20 | < - 40 |
| DENSITY (KG/M³) | 915 | 779 | 773 | 757 |
| CETANE INDEX | 50 | > 80 | > 75 | - |

Regarding the technology implementation, Vegan® perfectly fits standalone, integrated or revamped refinery environments. Axens' experience and customized approach help to evaluate the potential of the project.

Commercial plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Capacity | Product | By product | Hours in operation |
|---------------|------------|----------|---------------|--|-------------|---------------------|------------|--------------------|
| Total La Mède | Commercial | Start-up | 2019 | Lipidic feedstocks – customer confidential | 500 000 t/y | 1500 tonnes/day HVO | N/A | N/A |

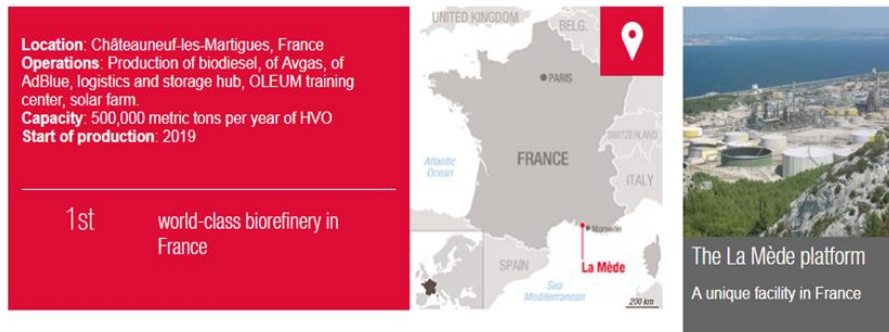
The TOTAL La Mède reference will be the first Vegan® unit in operation and extends decades of petroleum fuel production knowledge to the next generation of renewable biofuel production:



Vegan® can be easily tuned to match the required boiling range and cold flow properties of the desired product. Producers can thus balance production between Diesel or Jet fuel to meet market demand.

<https://www.total.com/en/energy-expertise/projects/bioenergies/la-mede-a-forward-looking-facility>

TOTAL La Mède: A Forward-Looking Facility



Source : <https://www.total.com/en/energy-expertise/projects/bioenergies/>

Established in India

Axens has been a market leader for technology licensing in India since the 1970's with more than 120 licensed units. After the recent takeover of Heurtey Petrochemicals, we offer a complete range of solutions including technologies, equipment, furnaces, modular units, catalysts and services for Refining, Petrochemicals, Renewables, Gas & Water. With two offices in Delhi and Mumbai and one manufacturing yard at Por, Baroda (Gujarat), Axens responds in an agile way to clients new requirements and market changes.

Contacts:

SAHA Siddhartha - Country Head - Sales & Marketing, Sales PCA

Siddhartha.SAHA@axens.net

CSIR-Indian Institute of Petroleum



Biofuel for Aviation – Sustainable Indigenous Development

Used cooking oils and non-edible oils valorization for bio-aviation fuels production have immense potential, with economic, societal and environmental benefits. CSIR - Indian Institute of Petroleum, Dehradun (CSIR-IIP), a research lab of the autonomous Council of Scientific and Industrial Research under the Ministry of Science and Technology, Government of India, has developed and demonstrated technology for production of renewable green aviation fuel from non-edible oils and waste oils.

The demonstration plant is based on a patented catalyst and process by CSIR-IIP (EP 3191565; US20170253808A1), produces bio-aviation fuel which is more energy efficient, economical and environment-friendly (<10 ppm sulfur, reduced NO_x and CO_x), meets ASTM D 7566 and ASTM D1655 (after blending with fossil-derived Aviation Turbine Fuel) as well as the IS 17081:2019 specification for Bio-ATF.

Besides production of green aviation biofuel, the technology also produces low sulfur (<10 ppm) diesel (80-90 cetane), renewable naphtha and light gases. Bio-jet yield is in the range of 25-30% by mass of the liquid product yield with H₂ consumption of about 0.03-0.05 MT H₂/MT oil processed.

The infrastructure for a CSIR-IIP Bio-jet plant is very similar to a conventional Hydrocracker unit. Till March 2019, CSIR-IIP has produced approximately 2600 litres of Bio-Aviation fuel. This has been supplied to Spicejet Ltd. for India's 1st Biofuel flight on August, 27, 2018 on the Bombardier Q-400 turboprop aircraft with PW150A twin engines (at 25% blend in one engine), and to Indian Air Force (IAF) for testing on the Russian Antonov AN-32, medium-range military transport aircraft with Ivchenko AI-20 Soviet turboprop twin-engine (10% blend). After successful trials and laboratory tests, the fuel produced at CSIR-IIP was used by the IAF during the Indian Republic Day fly-past on January 26, 2019.

Demonstration scale/Commercial plant established in India

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity (Tons / day) | Product (Tons/day) | Co-products (Tons/day) | Hours in operation |
|-------------------------|---------------|-------------|---------------|---|---------------------------------|--------------------------|---|--------------------|
| Bio-Aviation Fuel Plant | Demonstration | Operational | 2018-19 | Non-edible oils like jatropha, pongamia, used cooking oil | 0.24 | 0.04 (Bio-Aviation fuel) | A) 0.07 (Diesel); B) 0.02 (Naphtha); C) 0.002 (LPG) | 1200 hrs |



CSIR-IIP is the only institute in India, having a demonstration-scale plant established for the production of bio-aviation and renewable diesel fuels. A team of 40 trained personnel including scientists, technical staff and project assistants are working for its operation, maintenance, research and development and exploring the business potential

Contact:

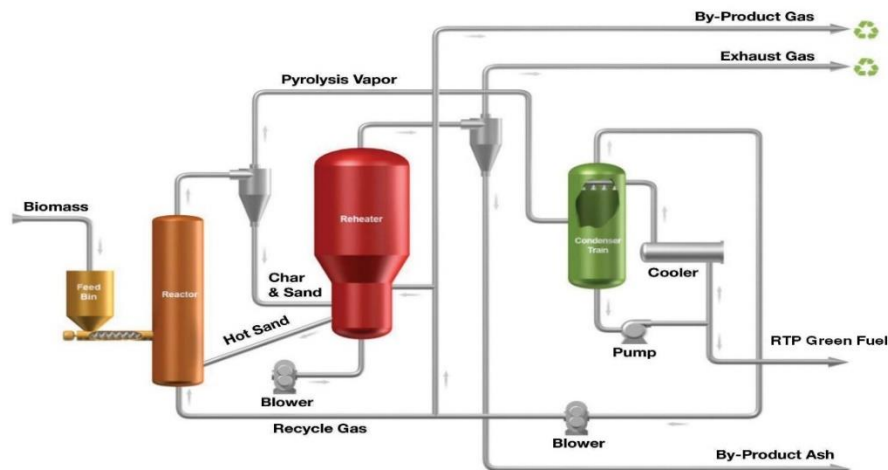
Dr. Anjan Ray, Director, CSIR-Indian Institute of Petroleum, Dehradun, India; director@iip.res.in

Technology developed- RTP™ Technology/ FCC Coprocessing

Envergent Technologies- A Honeywell Company offers a practical and commercially proven path to green fuel and green energy, capable of converting low value biomass into a high value liquid asset. Our RTP™ (rapid thermal processing) technology is a fast-thermal conversion process used to convert biomass feedstocks, usually agricultural or forest residuals, into Renewable Fuel Oil (RFO) or Bio-Crude - a light, pourable, clean-burning energy dense liquid biofuel.

Beauty of our Rapid Thermal Process (RTP™) lies in its simplicity. In less than 2 seconds, RTP process can convert a wide range of biomass feedstock into Renewable Fuel Oil. During the process, biomass is heated rapidly to approximately 500°C in the absence of oxygen. A circulating transported fluidized bed reactor system is at the heart of the process. A tornado of hot sand vaporizes the biomass, which is then cooled rapidly, typically yielding 65%-75% of RFO, a biofuel that has a potential to reduce GHG emissions by 79%-90% compared to fossil fuels.

A basic process schematic of the RTP technology unit can be viewed below:



RFO contains almost no sulfur and is virtually carbon-neutral. This energy dense, pourable liquid can be stored and shipped easily; unlike biomass which has its own challenges for storage and transportation due to low bulk density and low energy density. RFO can be used in a variety of application, such as space heating, residential or district heating, industrial process heating (furnace, kilns or boilers) or can be easily upgraded using UOP's FCC Coprocessing process into drop-in sustainable fuels like gasoline and diesel.

Status - Commercial installation since 1980's

On Commercial success front for the RTP technology, that is the backbone of this biocrude coprocessing pathway, our RTP process is behind World's biggest Biomass Fast Pyrolysis units ever built. Total 6 units have been operating in US and Canada for many years, with first commercialization that goes back to 1980's. Seventh unit which is also World's biggest Fast Pyrolysis unit, located at AE Cote Nord in Quebec, Canada is in the final stage of commissioning. Customer visits can be arranged at appropriate time to our commercial unit in Canada, if desired.

On FCC Coprocessing front, till date UOP has worked with numerous refining customers at various scales (lab, pilot plant, and commercial) to assess concerns related to integrating this technology into existing refining and downstream infrastructure, maintaining process equipment reliability and managing

consistent in-spec product quality. After 4 commercial scale co-processing trials and extensive stage-gate process over last few years since 2012, multiple full-scale commercial installation of FCC Co-processing technology is in progress in USA, Europe, Asia.

RTP Unit, Ensyn in Renfrew Canada



RTP Unit, AECN in Quebec, Canada



Established in India

On February 11th 2019, an MOU was signed by our customer Virgo Corporation with Punjab State Government in presence of Hon'ble Chief Minister Punjab Mr. Amarinder Singh and Hon'ble US Ambassador to India Mr. Kenneth I Juster. Proposed plan is for setting up World's Biggest Commercial RTP plant, capable of processing 400 Bone Dry MT/Day of surplus agri-residues such as Paddy Straw, wheat straw in the state of Punjab, which are otherwise burnt in the field causing environmental damage.

<https://in.usembassy.gov/u-s-embassy-celebrates-mou-u-s-company-supplies-technology-to-turn-crop-stubble-into-biofuel>

Contact: Dharmesh Mahajan, Bio-Renewable Business Development Leader (India & Africa)
Dharmesh.mahajan@honeywell.com

RE-CORD

(Renewable Energy Consortium for R&D)



Biomass Slow Pyrolysis in rotating kiln and fixed bed (oxidative Pyrolysis)

The systems developed allows for carbonisation of lignocellulosic biomasses and at the same time delivery of high temperature heat. Rotating kiln can process many different types of biomasses, from woody to herbaceous, while the fixed bed reactor can accept woody biomasses or briquetted/compacted materials. The rotating kiln system, developed in collaboration with our partner LineaRetta, is available at 100, 500, 1000 and 5000 kg/h size (feed at inlet), while fixed bed oxidative pyrolysis is available in the range of 50-250 kg/h. The rotating kiln system technology is suitable for integration in large scale supply chains for the production of advanced biofuel, providing heat for biomass drying as well as biochar for the soil. Technology supply from the EU, or know-how/transfer and manufacturing agreement with Indian companies are possible.

Status of technology: Commercial/Demo plant (rotating kiln)

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|-------------|----------|-----------|---------------|--------------|--------------------|-------------------------|------------|--------------------|
| TGE | C | Completed | 2005 | Wood | 1000 kg/h | 10-15 kg/h | Heat | - |
| Varese | D | Completed | 2010 | Wood | 50 kg/h | 10-15 kg/h | Heat | - |
| CC-Pyro | D | Completed | 2010 | Wood or RDF | 4 t/h | 1100 kW GT + 4500 kW ST | Heat | - |
| Meat & Bone | D | Completed | 2005 | MBM | 350-500 kg/h | Heat (diathermic oil) | Heat | - |
| Tecnoparco | D | Completed | 2008 | Wood | 500 kg/h | 250 kWe | Heat | - |
| Test | D | Completed | - | Various | 100 kg/h | Biochar | Heat | - |

Demo plant (Oxidative pyrolysis)

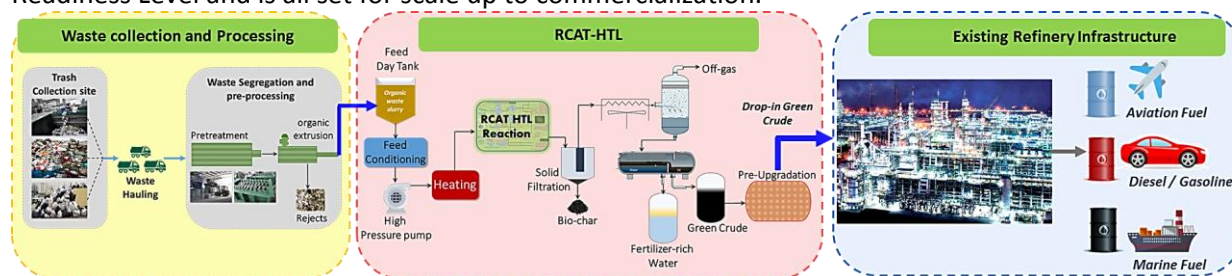
| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|------------|----------|-----------|---------------|--------------|--------------------|---------|------------|--------------------|
| CARBO | D | Completed | 2014 | Wood | 50 kg/h | 12 kg/h | Heat | - |



Established in India - Not yet established in India, as of March 2019. **Contact:** David Chiaramonti, RE-CORD President, david.chiaramonti@re-cord.org

Technology developed Reliance Catalytic Hydrothermal Liquefaction (RCAT-HTL)

RELiance CATALYTIC HYDROTHERMAL LIQUEFACTION (RCAT-HTL), a catalytic thermochemical process developed by Reliance Industries Ltd. (RIL), converts biomass, bio-waste, plastic waste and any organic waste into energy-rich drop-in green liquid fuel and recovers fertilizer-rich water from wet waste. Drop-in green crude from RCAT-HTL can be processed in the existing refining infrastructure, thereby avoiding the additional investment in new infrastructure. No change is required in the engine to use RCAT-HTL derived transportation fuel (aviation fuel, marine fuel, diesel or gasoline). This environmentally sustainable process overcomes the limitations of the existing technologies and offers a green solution to the global problem of waste disposal. RIL's RCAT-HTL is more feed-flexible – it can handle both dry as well as wet bio-waste, organic waste, mixed waste by co-processing or independently. RCAT-HTL uses catalyst and is an improvement over thermal HTL. RCAT-HTL offers immense flexibility on product profile to suit the market demand by tuning the kinetics of the reaction. RIL's RCAT HTL is at advanced Technology Readiness Level and is all set for scale up to commercialization.



Status

Demonstration scale

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|-----------------|----------|-----------------|---------------|---------------------------|--------------------|-------------------------------|------------------------------------|--------------------|
| Gagva, Jamnagar | D | Under operation | 2016 | Algae, food waste, sludge | 300 kg /d (dry) | Renewable crude 80-90 lit/day | Fertilizer-rich water and bio-char | 1250 |



RIL's RCAT-HTL demonstration plant at Jamnagar, India (Details in the above table)

Established in India

Reliance Industries Limited is a Fortune 500 company and the largest private sector corporation in India. The company is headquartered in Mumbai, India and owns businesses engaged in Refining & Marketing, Petrochemicals, Oil & Gas, Retail, Digital Services and Media & Entertainment. RIL has about 190,000 employees and manufacturing locations at Jamnagar, Hazira, Patalganga, Nagothane, Dahej and Vadodara. RIL has state-of-the-art R&D facilities with research spanning across refining, petrochemicals, catalysts, alternate energy, novel materials, bio-fuels, synthetic biology and nanotechnology.

Contact: Ramesh Bhujade, Vice President - R&D, Algae to Oil, ramesh.bhujade@ril.com



Shell International

Technology developed (IH²® Technology-a Conversion Technology for Biomass to Drop-in Fuels)

Shell intends to thrive through the energy transition. One way we will do this is by producing biofuels to reduce the net carbon footprint of the fuel we sell to our customers. Through the Raízen joint venture in Brazil, Shell is one of world's largest sugar-cane ethanol producers. Shell daily blends and distribute biofuels to meet government mandates. Shell are also developing advanced biofuels, as well as renewable natural gas (RNG), also known as biomethane, for use in natural-gas fuelled vehicles.

One advanced biofuel option Shell is pursuing is IH₂, a technology conceived by US-based Gas Technology Institute (GTI) and further developed in collaboration with Shell Catalysts & Technologies. The Technology in principle can convert agricultural residues, forestry residues and other wastes (e.g. sorted municipal solid waste) into lower carbon transportation fuels, including petrol, diesel and jet-fuel on a commercial scale. The process involves two steps comprising of Catalytic Hydrodeoxygenation of biomass in a gas-solid-solid bubbling fluidised bed reactor followed by hydrofinishing of the gaseous reaction mixture in a fixed bed gas-solid reactor post biochar separation. A schematic of IH₂ is shown in [Figure 1](#):

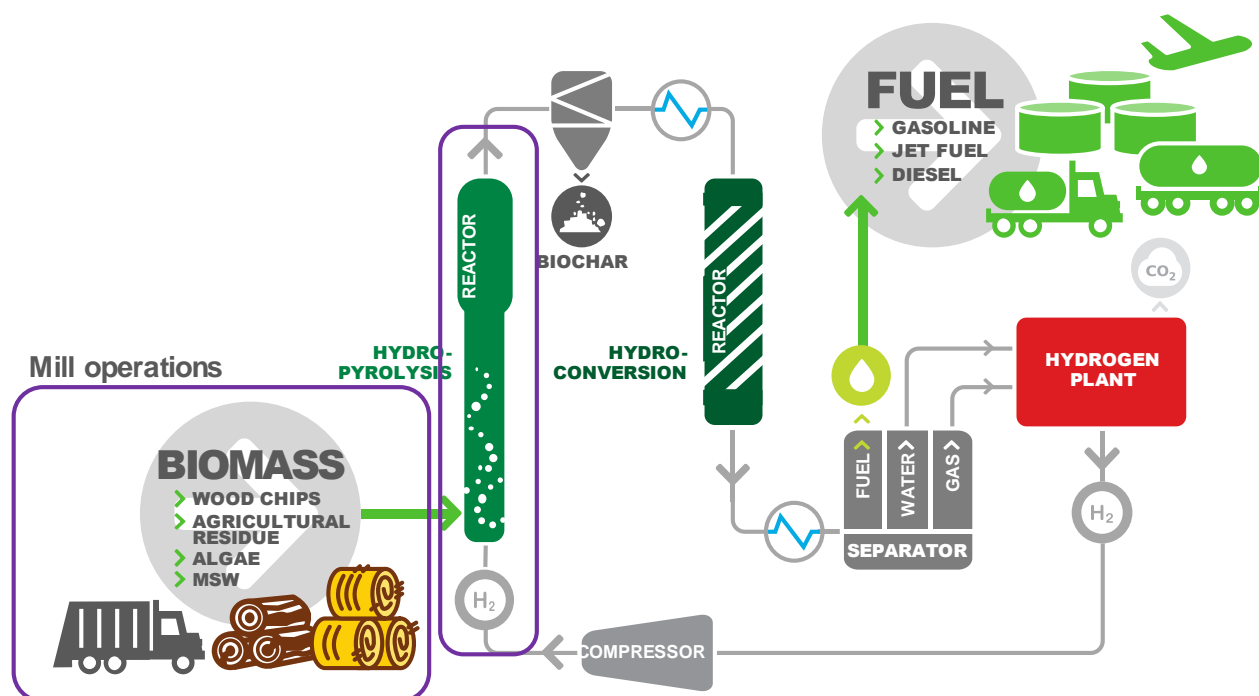


Figure 1 : Schematic diagram of a typical IH₂® plant with key process blocks

The iH2 technology has been successfully proven on a pilot scale. In 2017 a plant was completed at Shell's Technology Centre in Bangalore, in India, to technically demonstrate scale-up. The demonstration plant has a five tonne/day capacity and has completed several runs. The technology performance outcomes have been in line with what was expected. Following these initial runs, operations have been temporarily paused whilst necessary modifications are made to build the capacity for the plant to process higher amounts of feedstocks and run for longer periods of time. This activity will take a few months. Providing the plant works as we expect it to, Shell will collaborate with partners to commercialise the technology and make a successful business. The first commercial applications will process agricultural residues. In the future, we would also aim to use municipal solid waste.

Tests completed at pilot scale indicate that the iH2 process can recover up to 70% of bioenergy in the form of fuel and biochar. The gasoline and diesel from iH2® technology has GHG emissions reduction is estimated to be in the range 70-90% on overall Life cycle analysis basis compared to fossil fuels. A number of opportunities for first commercial deployment have been evaluated in different countries, including in Sweden, Norway, the Netherlands, Germany, USA, Canada and India. Significant business development work is underway to understand the availability of different types of waste, globally, its composition across regions, and its compatibility for use in the production of transport fuels. We are also looking to understand the relevant regulatory and fiscal regimes and sustainability issues, and how these feedstocks are currently managed by existing supply chains.

iH2® Technology Status (Under Demonstration)

5 TPD Demonstration scale

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|---|-----------------|---------------|----------------------|-------------------------|--|---|-------------------------|---|
| iH2 Shell Technology Centre, Bangalore | Demonstration | Commissioned | 2017 | Wood, Agri residue, MSW | 5 Tonnes/day (Moisture and Ash free Basis) | 1.3-1.4 tonnes/day drop in fuel when full capacity is reached | 0.6-0.75 TPD of Biochar | Commissioned in 2017, Product in Tank achieved. Plant enhancements underway. Planned to start back soon |

Contact: Mr. Andrew Murfin, General Manager, Advanced Biofuels - New Energies,

Shell International, UK

Email : Andrew.Murfin@shell.com

Technology developed

Swedish Biofuels AB is based in Stockholm, Sweden. Swedish Biofuels (SB) ATJ technology is a combination of proven industrial processes together with proprietary catalysts. In its patented process, SB converts forest and agricultural waste to syngas and alcohols and then further to the mixtures of hydrocarbons forming transport fuels and individual chemicals.

SB jet fuel technology has been demonstrated on a small scale, producing jet fuel continuously from a variety of sustainable raw materials since 2009. Jet fuel has been produced, tested and sold under contract with US Defense, US Federal Aviation Authority, US Volpe Center and Swedish FMV during 2009 - 2018. Tests performed by US AirForce and US FAA confirm that the jet fuels meet the Jet A-1, Jet A, and SP-8 standards. They comply with ASTM certification and are approved for use in commercial aviation under ASTM D7566-18.

The technology has great flexibility, allowing the use of existing syngas or ethanol production facilities to “bolt on” to SB processes. The bolt on approach widens the sustainable feedstocks for the SB process and reduces the capital cost for bringing jet fuel production on stream. SB has carried out feasibility studies and basic engineering for the bolt on concept using MSW to ethanol to jet fuel, straw to ethanol to jet fuel and off-gases to ethanol to jet fuel.

Other aspects of the flexibility of the technology concern the range of products that can be produced. Production can be dedicated to jet fuel or jet fuels can be produced in combination with other fuels and chemicals, without major technical modifications. Such flexibility considerably enhances the economic resilience of the production plant.

Alcohol-To-Jet (ATJ) fuels and blends

Status

Demonstration scale

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|------------|----------|------------------------------------|---------------|----------------------|--|--------------------|----------------------------------|--------------------|
| ATJAB | Demo | Detailed engineering / procurement | 2021 | 2G Ethanol Biogas | Ethanol 43.6 t/d Biogas 7.6 t/d | Biojet 14.5 t/d | Diesel & gasoline 14.5 t/d | |

Established in India

Through the EC setting up the EU-India conference on Advanced Bio Fuels in Delhi, India, a network has been developed, in India, including industry and research institutes, with the expectation of licence sales and cooperation to develop production facilities.

Contact: Angelica Hull, Managing Director, angelica.hull@swedishbiofuels.se

TechnipFMC, BTG-BioLiquids BV (BTL)

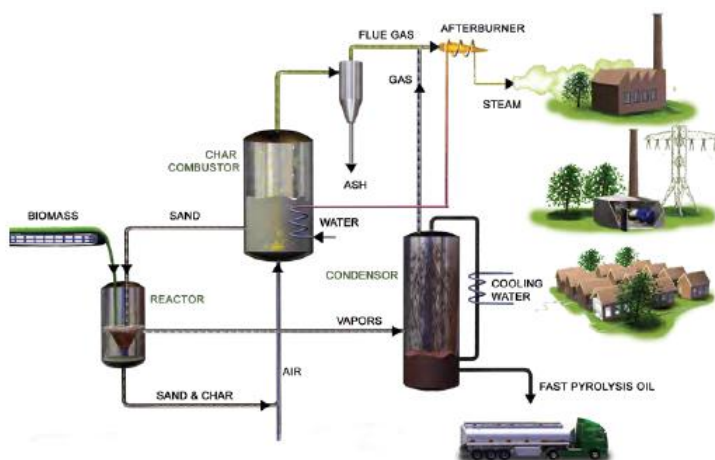
Fast pyrolysis bio-oil technology and production

BTL's fast pyrolysis technology converts waste biomass into a bio-oil product that serves as a fuel for heating purposes or as refinery co-feedstock to produce transportation fuels.

The technology is based on intensive mixing of biomass particles and hot sand in a reactor without air. Pyrolysis oil, gas and char are the primary products from the process. The char and sand are recycled to a combustor where the char is burned to reheat the sand. The vapors leaving the reactor are rapidly cooled in the condenser yielding pyrolysis oil and some gases. The gases and surplus heat from the combustor can be used to generate steam for power generation, biomass drying or external use.

Commercial plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|-------------------------|------------|--------------|---------------|--------------|--------------------|-------------------|---------------------|--------------------|
| Empyro, The Netherlands | Commercial | In operation | 2015 | Wood residue | 120 tons/day (dry) | 64,000 liters/day | Steam: 250 tons/day | Since 2015 |



Established in India

TechnipFMC is a global leader in subsea, onshore/offshore, and surface projects. Dutch based BTG-BioLiquids BV (BTL) is the technology provider of the fast pyrolysis process and has entered into a cooperation agreement with the Dutch branch of TechnipFMC to jointly realize projects for new customers. TechnipFMC has 3 operating centers in India with a workforce of about 3000 employees and is ready to contribute to the roll-out of the technology for the Indian market by providing local EPC services.

Contact: Koos Overwater, VP New Technologies, koos.overwater@technipfmc.com

ThermoChem Recovery International



Waste biomass to diesel and jet fuel

Thermo-chemical biorefinery systems are the only available conversion technology that can process a wide range of biogenic feedstocks and can be built to economically profitable scales, operate continuously and achieve high-conversion energy efficiencies while providing superior environmental solutions. TRI's proprietary systems provide feedstock flexibility which enables bioenergy operators to vary input based on comparative costs or BTU content (i.e., the lowest delivered cost of carbon to the plant gate) allowing maximum profitability during changing market conditions. The TRI system is fully scalable from 500 to 2,000 dry tons per day of biomass with a single steam reforming vessel

The TRI gasification system utilizes an indirectly heated medium temperature, low pressure fluidized bed steam reformer primary stage and a higher temperature, low-pressure fluidized bed gasifier second stage to generate syngas. TRI has demonstrated that the technology can transform waste wood and everyday garbage into jet fuel using proven and mature Fischer-Tropsch conversion technology. Using garbage, waste wood, energy crops, agri-waste, animal waste, etc. we can create gasoline, jet fuel, diesel, chemicals, green power and other renewable energy.

Status: Demonstration plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|------------|---------------|--------------|---------------|-------------------|--------------------|-----------------------|------------|--------------------|
| Durham | Demonstration | In operation | 2009 | All waste biomass | 4 dry tons per day | Fischer-Tropsch Fuels | Various | 13,000 |

Demo Plant is located in Durham, North Carolina, USA



Status: Commercial plant

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|------------|------------|--------------------|---------------|--------------|----------------------|--------------|--------------------|--------------------|
| Sierra | Commercial | Under Construction | 2020 | Sorted MSW | 500 dry tons per day | SPK Jet Fuel | 10 MM gallons/year | N/A |

Project Sierra is located in Reno, Nevada, USA.



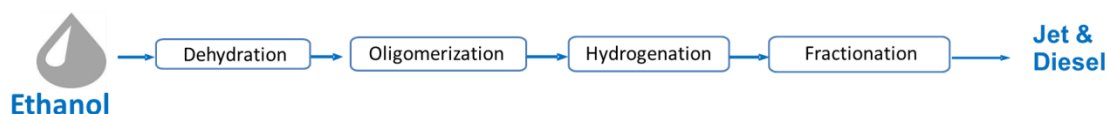
Contacts:

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Technology developed: Alcohol to Jet

Pacific Northwest National Laboratory and LanzaTech have developed an Alcohol to Jet (ATJ) process to make sustainable aviation fuel and diesel from ethanol. This ATJ process can use ethanol from any source including advanced non-food/non-feed ethanol and can be tuned to produce the desired ratio of drop-in jet and diesel fractions. In the LanzaJet ethanol based ATJ process, ethanol is chemically converted to synthetic paraffinic kerosene (SPK) via the four steps defined in ASTM D7566 Annex A5 for ATJ-SPK: dehydration, oligomerization, hydrogenation and fractionation. The ATJ-SPK product from LanzaTech's process was evaluated in the OEM led fit for purpose process and is qualified for use in commercial aviation at up to 50% blend with conventional jet fuel.



The SPK jet blendstock is a stable, wide boiling, paraffinic kerosene that has superior properties to conventional jet fuel. The remaining fraction is high-quality synthetic paraffinic diesel (SPD) meeting the requirements of the Euro 6 or BS-VI standards. The ethanol-based ATJ pathway originated at the Pacific Northwest National Laboratory (PNNL) in a collaboration with Imperium Renewables, Inc. that began in 2010. The technology was then refined with funding supplied to LanzaTech, PNNL and Imperium by the US Department of Energy. After five years of R&D efforts in PNNL's laboratory, and LanzaTech's process scale-up and optimization, the first demonstration scale unit was operated at LanzaTech's Freedom Pines facility in Georgia, US. This facility produced 4,000 USG of jet and 600 USG of diesel.

Status

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|-------------------------|----------------|----------------------|---------------|--|--------------------|----------------------------|------------|--------------------|
| LanzaTech Freedom Pines | D | Completed operations | 2015 | Ethanol from grain and steel mill flue gases | N/A | 50,000 USG/year equivalent | N/A | 15,000 |
| LanzaTech Freedom Pines | Pre-Commercial | Engineering | 2020 | Ethanol from diverse sources | N/A | 10M USG /year jet + diesel | N/A | N/A |
| LanzaTech UK | C | Engineering | 2022 | Ethanol from wastes and residues | N/A | 30M USG /year jet + diesel | N/A | N/A |

Established in India

LanzaTech India Pvt Ltd is a wholly owned subsidiary of LanzaTech, headquartered in Gurgaon. LanzaTech India is led by Mr. Sangeet Jain and currently has 6 business development and engineering staff. LanzaTech has licensed its gas fermentation technology to IndianOil for implementation at the IOCL Panipat refinery. LanzaTech anticipates additional projects will be executed in India through licensing to public and private sector refining, steel and other manufacturing companies and is exploring opportunities for production of sustainable aviation fuel in India from indigenous ethanol sources.



LanzaTech Freedom Pines (Georgia, US)

LanzaTech Freedom Pines is the site of LanzaTech's ethanol-based ATJ demonstration production and process optimization. A portion of the ATJ from the demonstration facility was used to power a commercial flight operated by Virgin Atlantic from Orlando, Florida to London in 2018. The Freedom Pines site is also the location of the next-scale pre-commercial plant (10M USG per year of jet and diesel products) which is currently in the engineering phase.

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CARBON CAPTURE & UTILISATION

Power to Liquids

Blast furnace gases

Air Liquide Global E&C Solutions

Technology developed PtL - CO₂ to MeOH

Air Liquide Engineering & Construction is the engineering and construction business unit of the Air Liquide Group. Innovation is applied to a comprehensive portfolio of proprietary technologies see: <https://www.engineering-airliquide.com/de/technology-handbook>

With it's Lurgi technologies Air Liquide has a long history of expertise with the Lurgi MegaMethanol™ technology and more than 60 methanol licenses for a total capacity of more than 47 million tonnes per year of methanol production. One of the major trends in recent years is CO₂ utilization by producing methanol with the addition of hydrogen from regenerative sources namely H₂ from electrolyzers with renewable electricity. The reduction of CO₂ footprint as well as the valorization of CO₂ rich gases are of increasing interest for many industries and methanol is a perfect fit for energy storage, for clean fuels and as a building block for producing high value chemicals. The application of CO₂ to methanol technology must be seen in the context of current and future environmental regulations. The CO₂ to methanol process can be implemented now with established technology offered by Air Liquide Engineering & Construction, complete with full commercial performance guarantees.



Process Development Unit for MeOH

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | Hours in operation |
|--------------------|---------------------|--------------|-------------------------------|--|---------------------------|---------|-----------------------|
| PDU - Frankfurt | Development Unit | In operation | CO ₂ -MeOH 2017 | CO ₂ +H ₂ or syngas | 10 Nm ³ /h) | 150kg/d | 9000 hrs |

Established in India

The Indian office of Air Liquide E&C is located in New Delhi. From this office, we execute engineering of various projects based on our proprietary technologies. Recently, AL E&C India has been active in the area of air separation plants, nitrogen plants, oleochemical units, steam methane reforming units, and gas sweetening units.

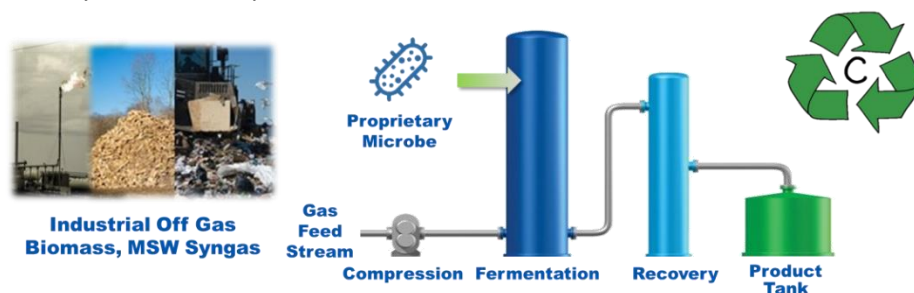
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Technology developed

LanzaTech's technology produces ethanol and other chemicals from gases containing CO, CO₂ and H₂. The process, known as gas fermentation, recycles carbon in waste streams using robust proprietary microbes that consume offgases from industries such as steel and refining or syngas produced from biomass residues and non-recyclable municipal wastes.



LanzaTech's technology has been demonstrated at five industrial sites with over 40,000 hours of operation using steel mill offgases (BlueScope Steel, NZ; Shougang Steel, CN; BaoSteel, CN; China Steel, TW). It has also been demonstrated for over 40,000 hours using syngas from industrial MSW gasification (Sekisui, JPN) and 120 days of continuous integration operations on syngas from waste wood and agricultural residues (Aemetis, US). On May 3, 2018, LanzaTech initiated commercial operations of a facility with a capacity of 46,000-tonnes per year of ethanol from steelmaking offgas (see Figure below). The Shougang-LanzaTech facility has produced over 20 million liters of ethanol as of March 2019.

Status

| Plant name | Type D/C | Status | Start-up year | Biomass type | Feedstock capacity | Product | By product | Hours in operation |
|-------------------------------|----------|--------------|---------------|-----------------------------------|---------------------|----------------------------|--|--------------------|
| Shougang-LanzaTech (China) | C | Operating | 2018 | Microbes fed by steel offgas | N/A | 46,000 tonnes/year ethanol | 5,000 tonnes/year animal feed 150,000 mmbtu/year biogas | >7,000 |
| ArcelorMittal (Gent, Belgium) | C | Construction | 2020 | Microbes fed by steel offgas | N/A | 62,000 tonnes/year ethanol | n/a | N/A |
| IndianOil (Panipat) | C | Engineering | 2020 | Microbes fed by refinery offgas | N/A | 34,000 tonnes/year ethanol | 1,000 tonnes/year animal feed 20,000 mmbtu/year biogas | N/A |
| Swayana (South Africa) | C | Engineering | 2020 | Microbes fed by ferroalloy offgas | N/A | 52,000 tonnes/year ethanol | 5,000 tonnes/year animal feed 60,000 mmbtu/year biogas | N/A |
| Aemetis (California) | C | Engineering | 2020 | Orchard waste | 125,000 tonnes/year | 35,000 tonnes/year ethanol | 3,500 tonnes/year animal feed 40,000 mmbtu/year biogas | N/A |

Established in India

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Shougang-LanzaTech commercial facility located at the Jingtang Steel Mill outside Beijing.

The facility converts carbon-rich offgases from steelmaking into ethanol, which is used for blending in the petrol market for road transport. The facility also produces a high-protein biomass co-product which is being supplied to the animal feed market, as well as biogas which is used at the steel mill.

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