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Advanced Liquid Biofuel from Biomass using RCAT-HTL

Ramesh Bhujade

RIL R&D

3RD EU-INDIA CONFERENCE ON ADVANCED BIOFUELS
NEW DELHI

European Commission

March 4, 2020

Reliance R&D at a Glance

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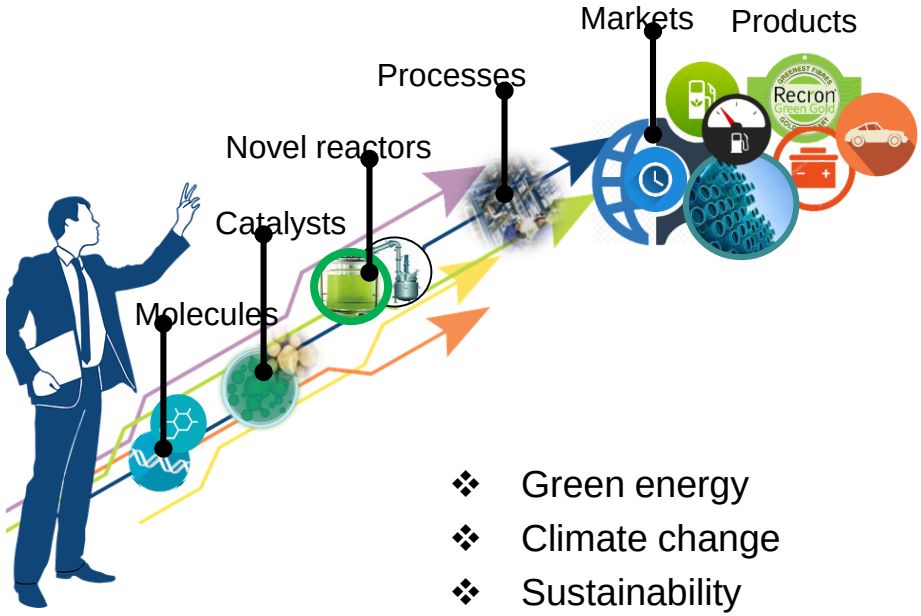
- Fortune Global 500 company.
- Refinery Complex: Largest in the world.
- 120 patents granted/164 patents filed (2018-19)
- 24 state-of-the-art labs. 900+ scientists and engineers in R&D and Tech
- *Breakthrough R&D using Algae platform technology – Sustainable source of biofuels, bio-chemicals and nutritional products*



- Green energy
- Climate change
- Sustainability
- Decarbonization

RCAT- HTL, *spin-off technology* from algal research is a Green Thermochemical process, providing sustainable solution for decarbonization

RIL R&D has end-to-end presence in value chain from feed stocks to valuable products

Advanced Liquid Biofuel for Decarbonization

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3 Most Important environmental goals

- Climate action
- Clean energy
- Sustainable cities

Climate change effects

Clean/Renewable energy

Transportation, major GHG contributor

- Road Transport: EVs helping reduce GHG
- Aviation, Marine and Long haul transport
  - **Liquid fuel** will continue to be used
- **"Drop-in"** advanced liquid biofuel helps utilize existing infrastructure
- Advanced Liquid Biofuel from **Algae, Waste biomass: Sustainable feedstock**

CO_2 to Algae, Waste Biomass as Sustainable resource for Decarbonization

- Algae, highly productive biomass
- 2 bn tons solid waste (2016), **3.7 bn tons** (2050)! *World bank report 2018*
- >70% of waste dumped, landfilled. Improper waste treatment produces Methane, 25x potent GHG than CO2!
- **Waste has inbuilt Energy, Water and Nutrients.** All are lost, when waste is not treated

Liquid biofuel from Algae and Waste Biomass for Energy Security and Climate Change Mitigation

Algae to Oil (A2O) and Bio-products

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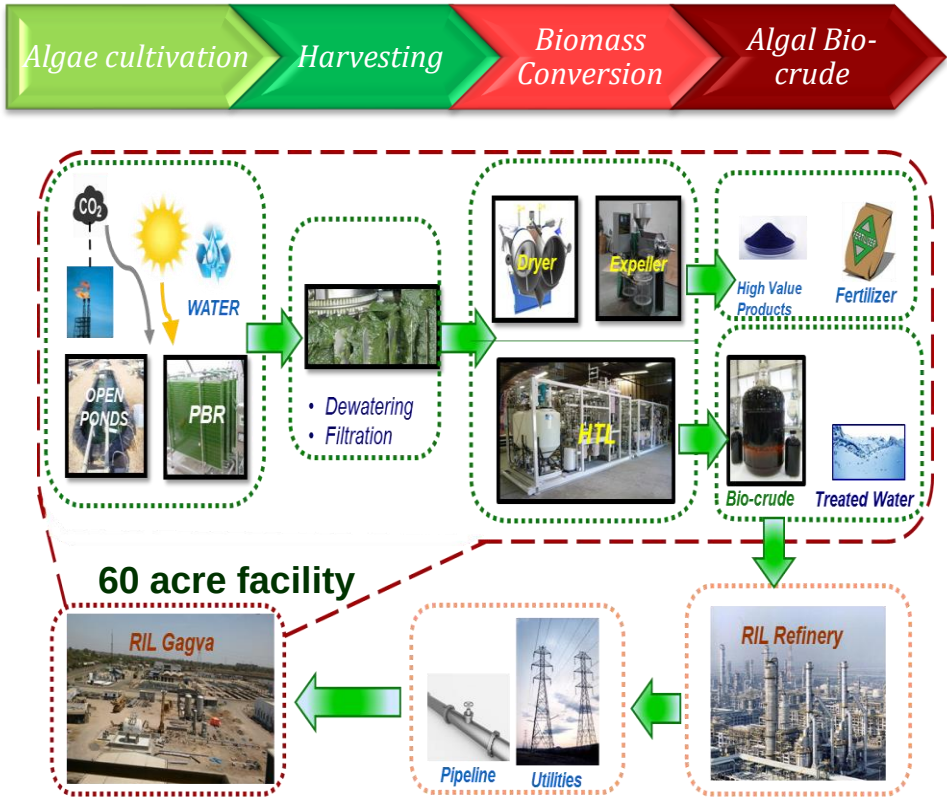
- CO_2 management
  - Capture, transportation, distribution, dissolution, LCA
- Cultivation Systems
  - Open ponds, R-PBR
- Harvesting / Dewatering
  - Chemical, Membrane, Centrifuge
- Dryer / Extraction
  - Aqua-feed, proteins, bio-products
- Wet algae conversion
  - RCAT-HTL, patented technology
- Utilities / Off-sites
  - Seawater, CO_2, Utilities, Storage



World's Largest Operating Algae to Oil Facility System since Dec 2016

A2O at a Glance

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End-to-End Operation in Industrial set up helped address many scale-up risks

A2O - First to the World Innovations

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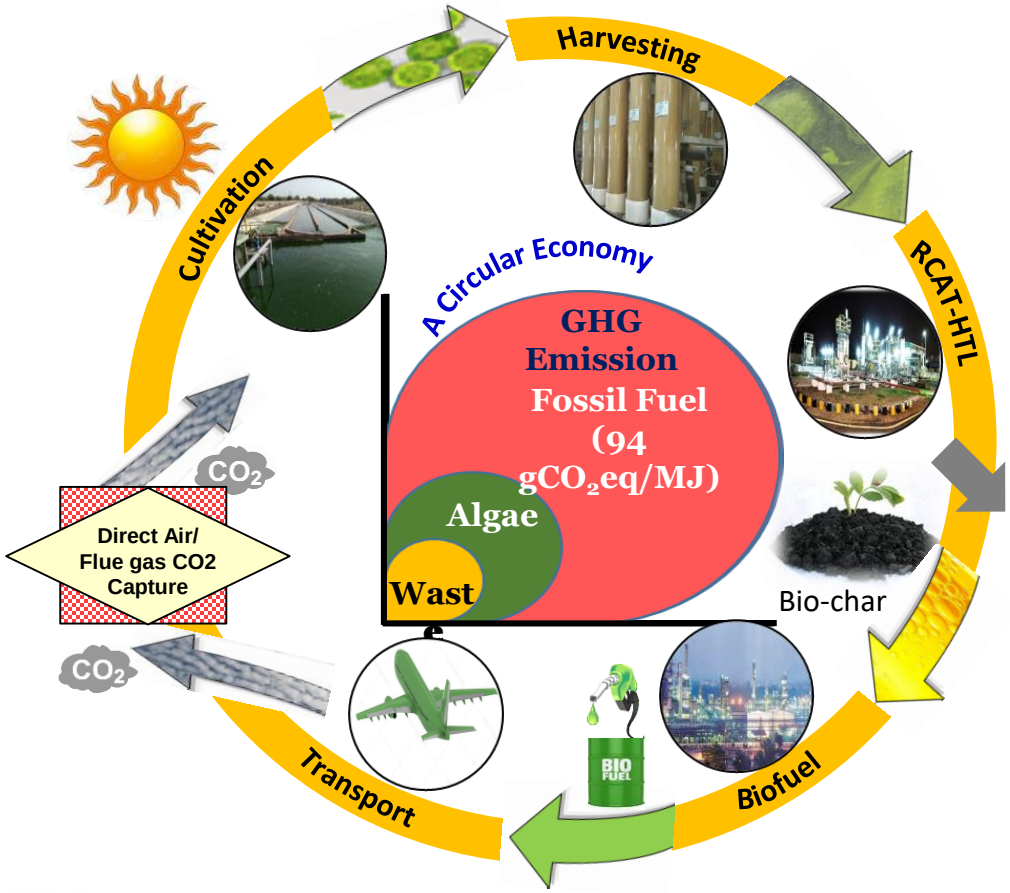
- First largest, Algae to Oil pilot plant
- Robust Algae strains
  - 30+ months operation w/o crash
- Photosynthesis Kinetic models
  - Designed R-PBR and Novel Ponds
- Innovative CO_2 management
  - Value chain Optimization
- Harvesting/Dewatering/Drying
  - Water recycle, No fertilizer run-off
- **RCAT-HTL**
  - Uses water in waste as reactant. No need of drying biomass
  - Recovers fertilizer-rich water
  - Most energy efficient technology



Large scale Utilization of CO_2 through Algae platform for Circular economy

RCAT-HTL: Feed flexible & Resource Efficient

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Demo Plant 2 TPD
(10-20% solids)

Algae | Food Waste | MSW Organics

Agro Residue | Industrial Sludge

Operational since 2016 at Jamnagar, India

0.5 bpd drop-in renewable fuel

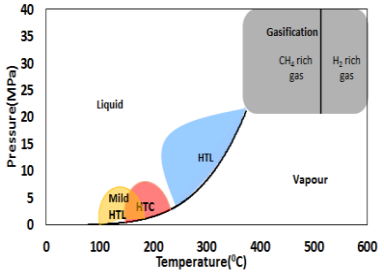
CO_2

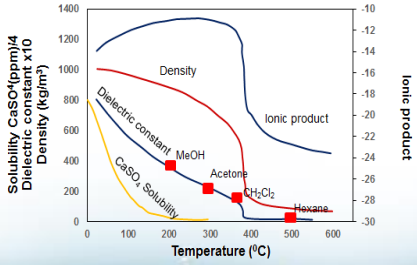
Upto 85% CO_2 emissions saving

Drop-in Green Crude

Renewable Transportation Fuel

Fertilizer rich water | Biochar | Sustainable farming | Ecofriendly Cosmetics





Algae to oil → Waste to Biofuel/Bio-products

1st HTL Expt.

Dryer/Expeller Solvent Extraction

Catalyst Development

RCAT-HTL ~~CHG~~ Reaction Pathways

Engine testing, Certifications

2012 | **2013 - 2016** | **2017 - 2020** | **Commercialization**

35+ Patents

~~Expeller~~ ~~Solvent Extraction~~ HTL + CHG

Kinetics & Molecular Model to predict yield

Biocrude upgradation

GOLDEN PEACOCK AWARDS Winner of Eco-Innovation 2018

Water as Solvent | No need of drying wet waste | Energy recovery > 70% | Drop-in liquid fuel

RCAT-HTL: Resource efficient technology

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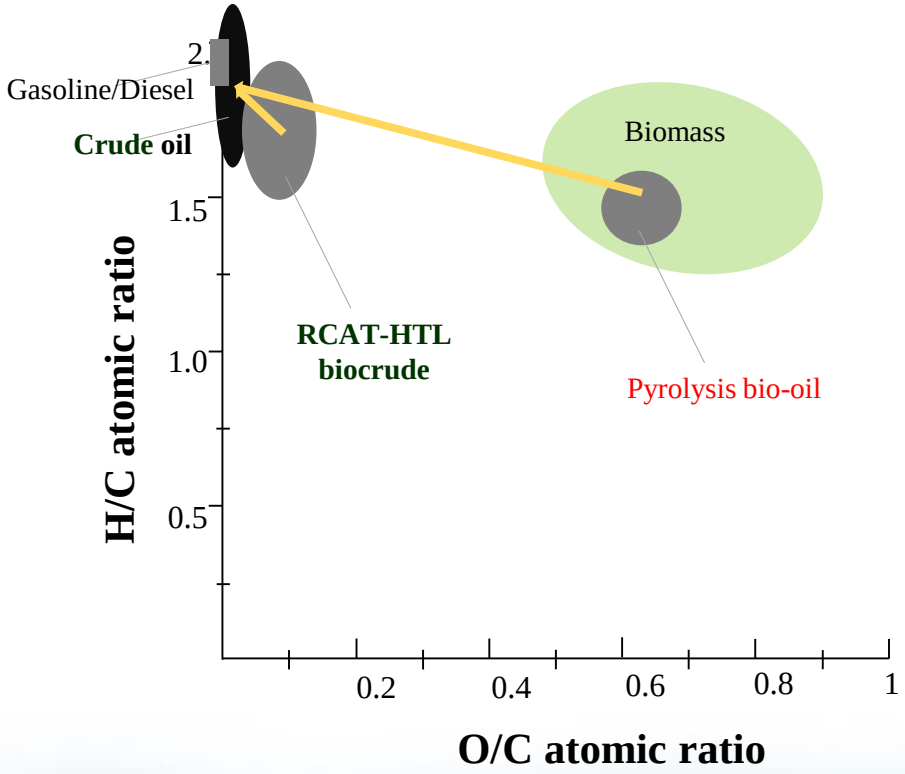
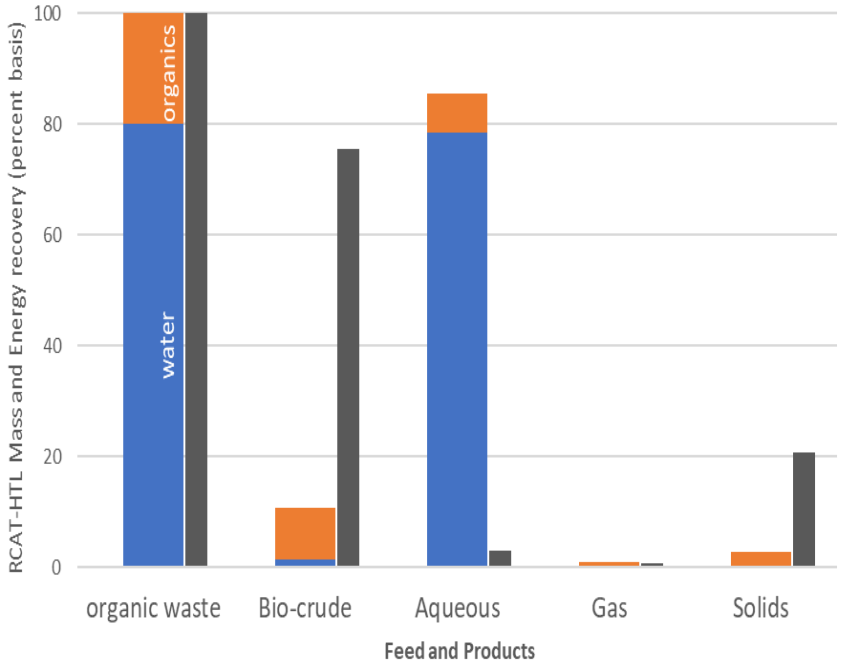
Biomass and Waste Biomass contain 50-80% water. Conventional thermochemical processes (RTP, Gasification) need dry biomass. RCAT-HTL utilizes water to convert biomass to advanced liquid biofuel





Energy in Bio-crude > 70% of feed

RCAT-HTL enables full use of Biomass – Energy, Water and Nutrients in Biomass

Biocrude composition: Thermochem processes

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Parameter	Fast pyrolysis	Catalytic pyrolysis	HTL
Heating Value, MJ/Litre (HHV)	21.52	32.3	35.87
Density, g/litre	1,197	1,168	1,120
Aromaticity, %	42.9	63.9	60.9
pH	2.66	3	4.53
Pour point, °C	-36	-6	33
TAN, mg KOH/g	125	82.6	28.6
Water content, wt %	25.7	7.6	5.6

UBC Bioenergy/Forest Products Biotechnology Group

Source: Assessment of likely Technology Maturation Pathways for biojet production from forest residues, March 2019. http://task39.ieabioenergy.com/

ATM/HTL biocrude upgrading: Key Conclusions

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- Biojet fuel successfully produced from HTL biocrude via the two upgrading pathways
- The Biojet fraction meets the majority of general ASTM specifications
- Possible emission reductions of up to 71.3% are possible
- Techno-economic assessment was reasonable compared to other potential biojet fuel pathways (e.g. alcohol to jet, HEFA biojet, FT biojet, sugar to biojet)
- HTL biocrudes were more stable, less corrosive, had a higher energy density and were "conducive" to one stage hydroprocessing
- However, "Nature" of the feedstock needs further study

UBC Bioenergy/Forest Products Biotechnology Group

Source: Assessment of likely Technology Maturation Pathways for biojet production from forest residues, March 2019. http://task39.ieabioenergy.com/

HTL Expert Workshop, Brussels 2019

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- Objective: Technology status, Market situation and Challenges
- Challenges:
- Aqueous phase disposal, Material of construction, product standards, Carbon pricing
- Conclusion:
- Compared to other technologies such as pyrolysis and gasification, HTL is a more robust technology as it can handle broader feedstock quality ranges

Horizon 2020

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steeper ENERGY

Southern Oil

Pacific Northwest National Laboratory

eni

MURA

Source: http://www.besustainablemagazine.com/cms2/expert-workshop-potential-of-hydrothermal-liquefaction-htl-routes-for-biofuel-production/

Co-operation among the stakeholders will help expedite commercialization

RCAT-HTL: Catalyst Development at RIL

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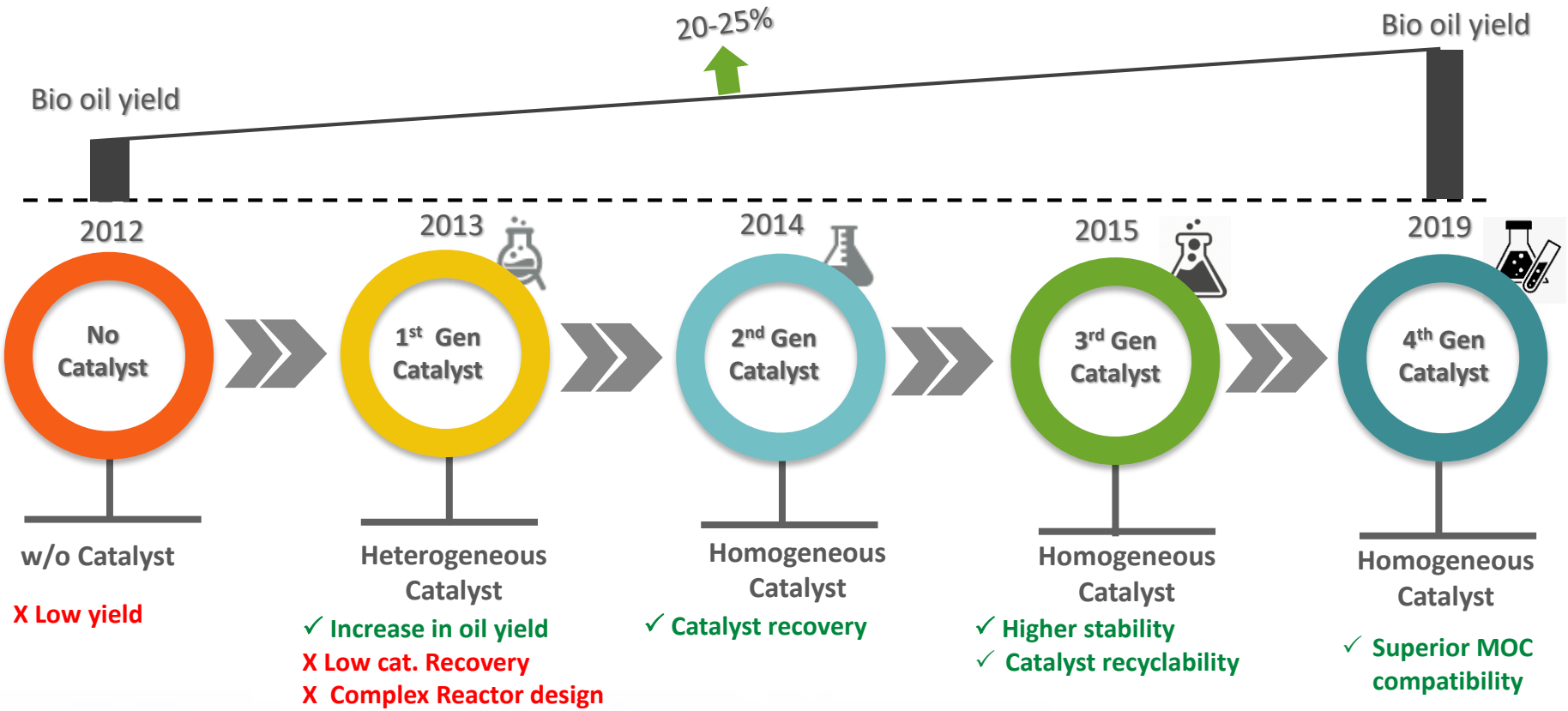
RCAT- HTL, spin-off technology from algal research. It provides sustainable solution for wet waste valorization. Over 125+ Homo- & Heterogeneous catalysts evaluated



Current 4th Gen Catalyst increased bio-oil yield by 20-25%

Mathematical model, Ideal tool for viability studies

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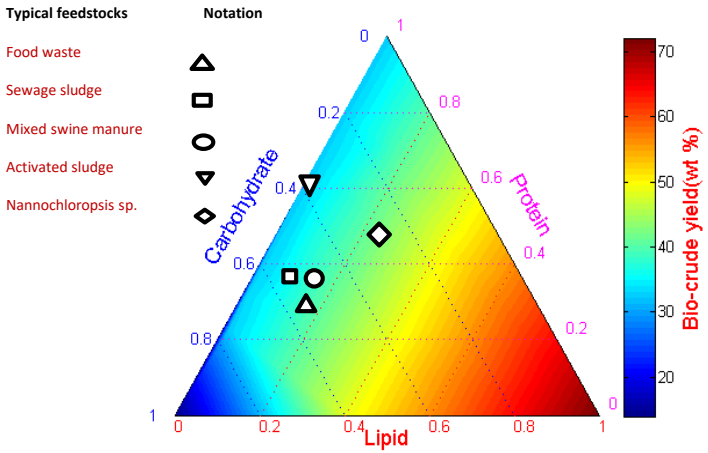
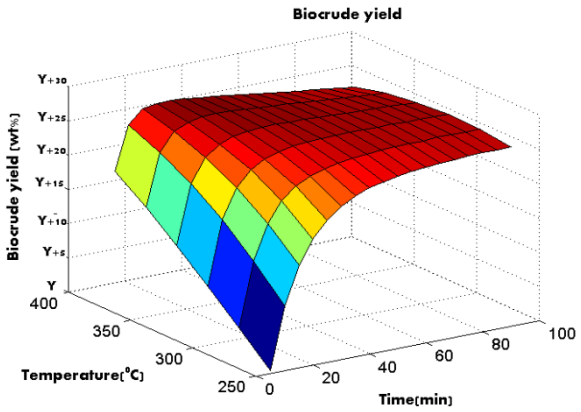
Composition of biomass and other waste varies widely. Process needs to be flexible enough to suit varying composition. HTL offers this advantage. Artificial Intelligence (AI) based model is being developed

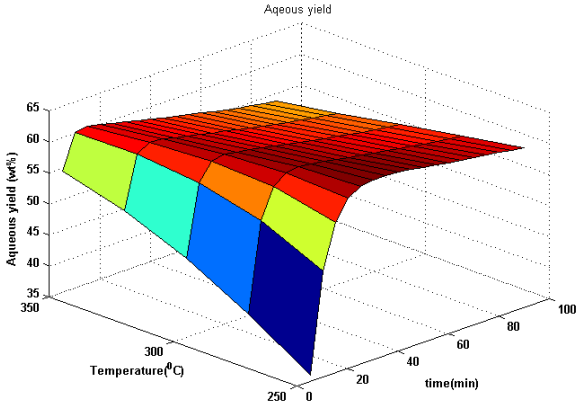
Biocrude yield Vs Feed Composition



Biocrude yield Vs HTL temperature



Aqueous yield Vs HTL temperature



Nonlinear kinetic model developed to optimize HTL process conditions

RCAT-HTL Aq. Phase as fertilizer-rich water

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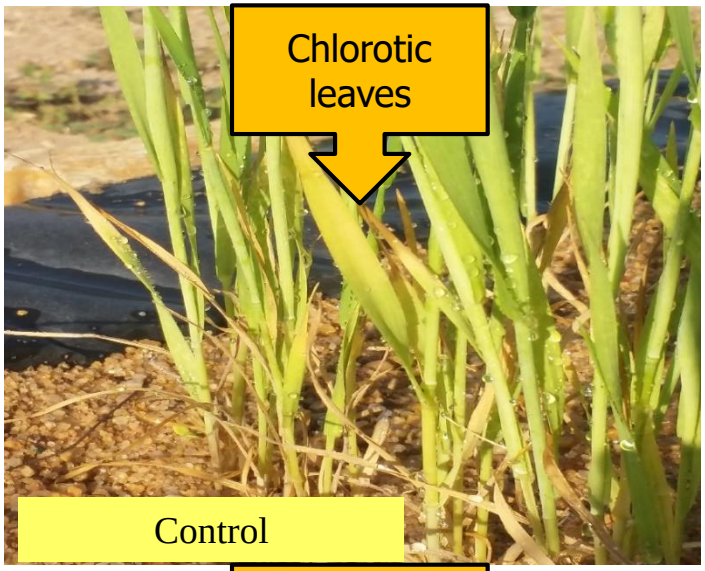

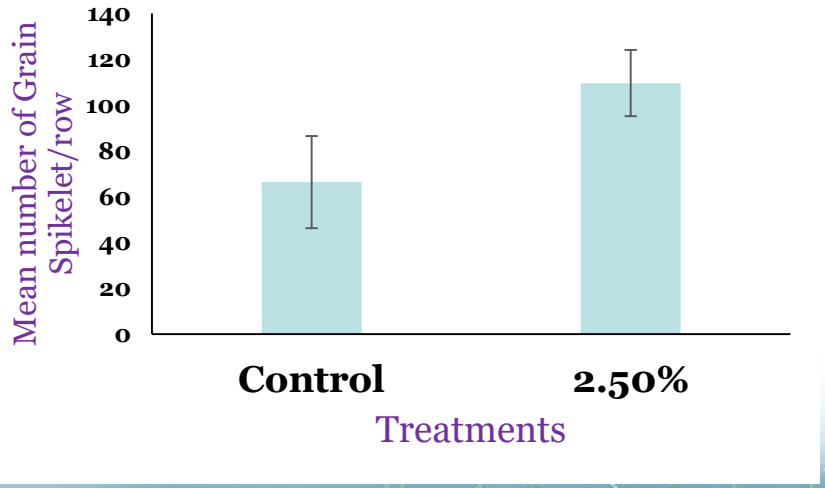

Significant enhancement in plant growth, health, and productivity

RCAT-HTL bio-crude characterization

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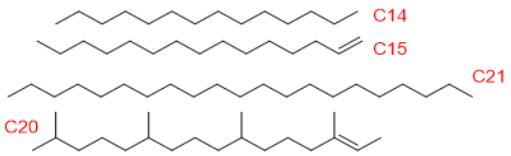
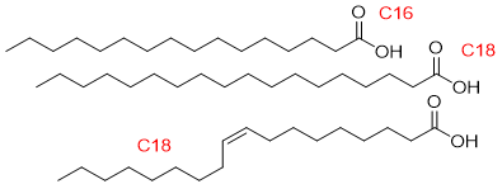
GC-MS data of a typical Algae CBO

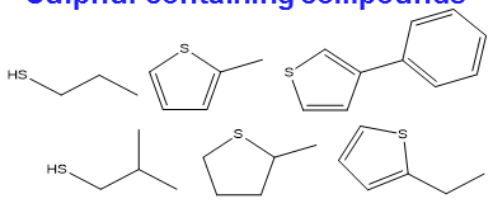
Alkanes and olefins



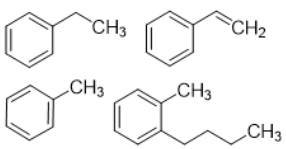
Fatty acids



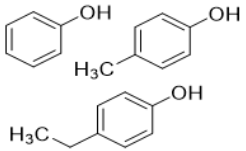
Sulphur containing compounds



Small Aromatics

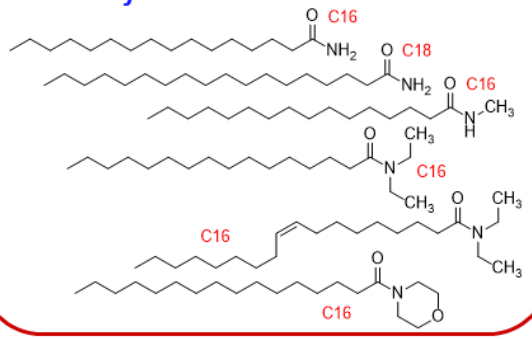


Phenols

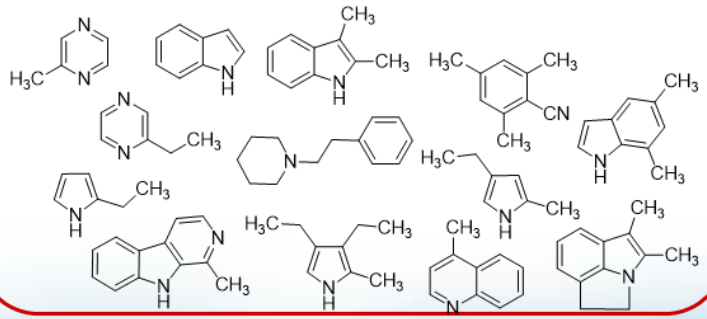


Compounds observed in CBO can be grouped according to the functional groups

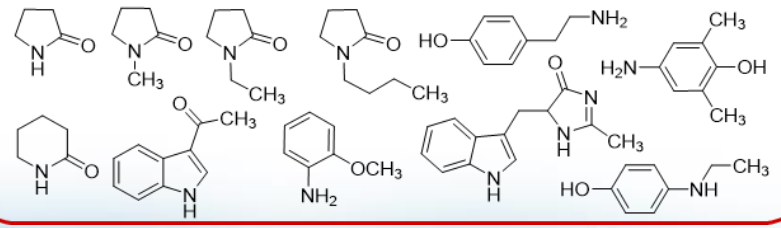
Fatty acid amide derivatives



Nitrogen containing heterocyclic compounds



Nitrogen & Oxygen containing heterocyclic compounds



Major functional groups in the CBO components – valuable biochemicals and transportation fuel precursors

Drop-in strategy for co-processing

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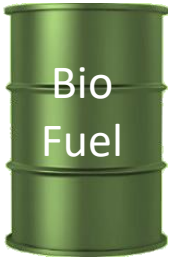
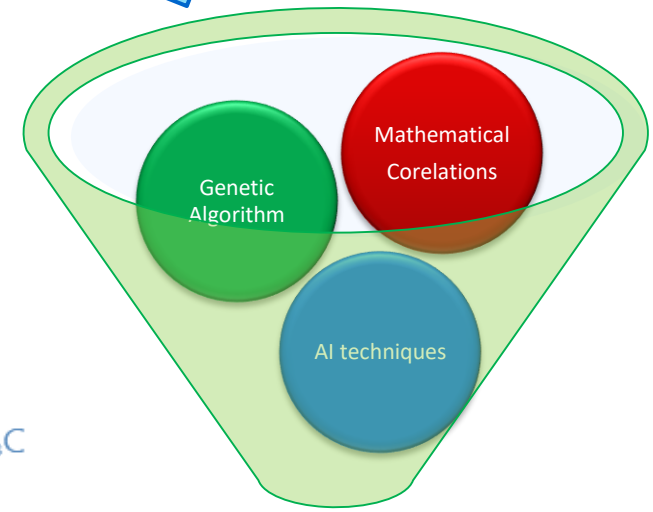
Bulk Properties

- CHONS
- Density
- Boiling Point



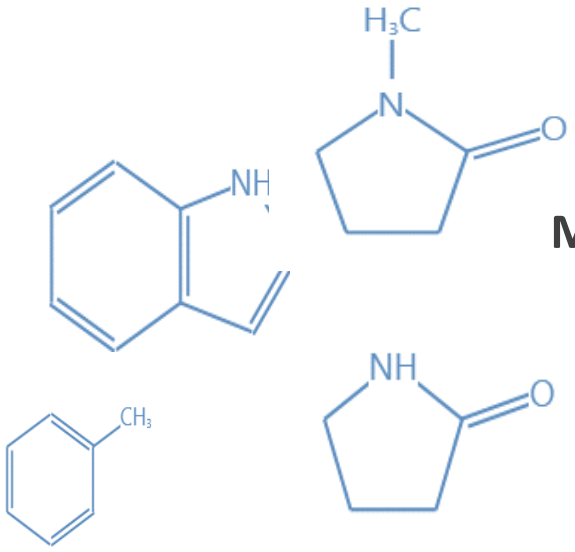
Mathematical Model



Refinery Integration Strategy

- Hydrotreatment
- Hydrocracking
- Feed to FCC

Molecular Information



Mathematical Model helps optimize integration of Bio-Fuel stream within existing refinery

Refinery Integration of Drop-in renewable fuel

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Green Crude from RCAT HTL → **Refinery Integration**

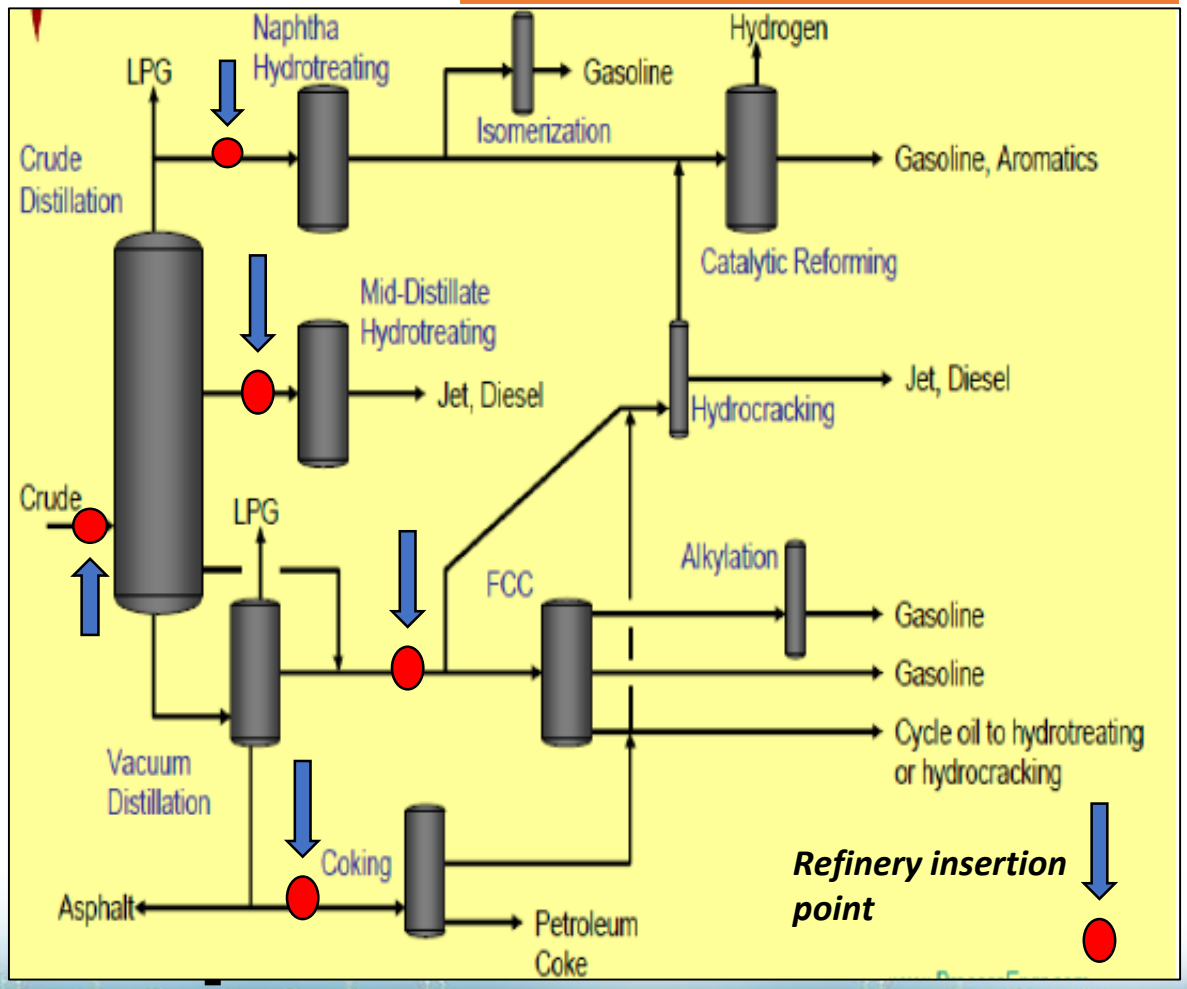
RCAT-HTL

Renewable Crude

Pre-treatment

Drop-in Crude

Feed for Refinery integration



Energy-rich & drop-in renewable fuel makes process economically sustainable

RCAT-HTL Innovations

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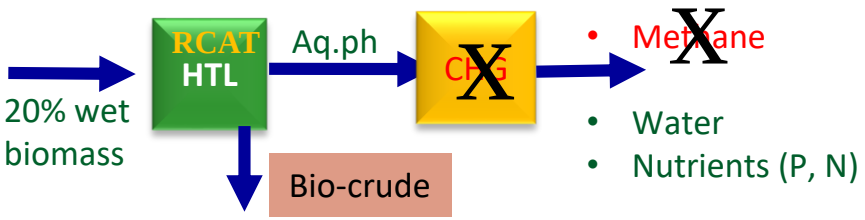
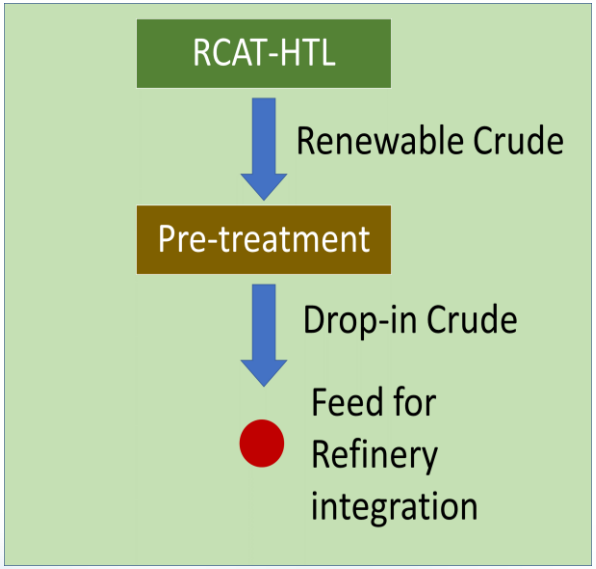
- Conventional HTL needs aq. phase treatment for reuse (e.g. CHG)
- RCAT-HTL maximizes C, H recovery to oil phase. Eliminated expensive CHG
- Aqueous phase usable as nutrient-rich water
- Molecular level understanding of HTL kinetics. Developed kinetics models to predict yield and compositions
- Technology ready for commercialization
- Drop-in bio-crude can be processed in existing refinery and engines

RCAT-HTL Eliminates CHG





Elimination of CHG for aqueous phase treatment is the major breakthrough in HTL technology

RCAT-HTL, for Advanced Liquid Biofuel

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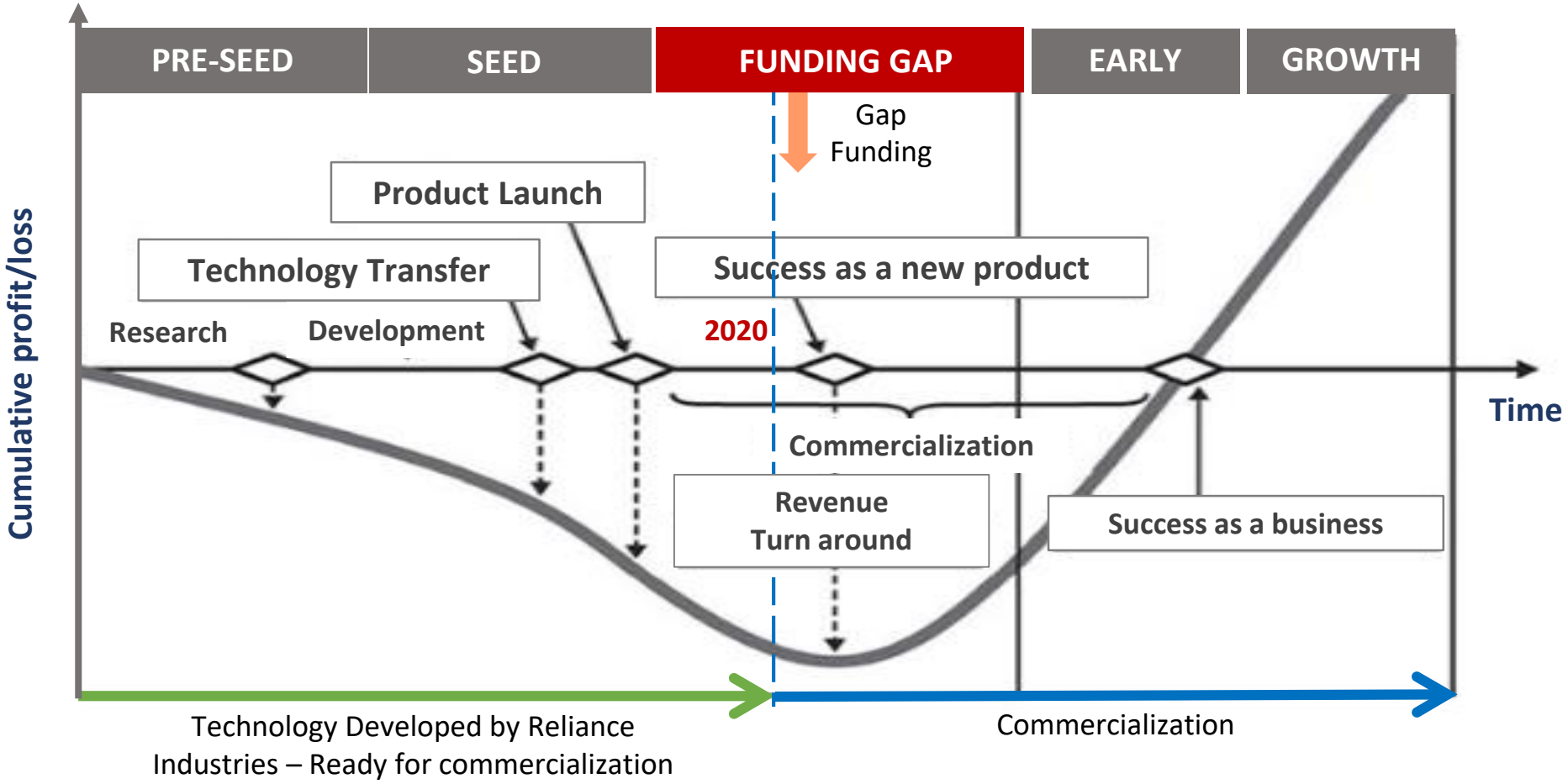

Catalytic HTL, Innovative technology proven by RIL at larger scale is ready for commercialization

RCAT-HTL Commercialization Road map

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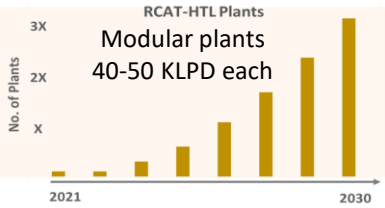
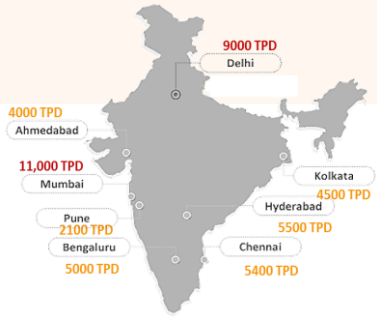
Growth Potential



IRR 15-20% (n^{th} plant)
Advanced liquid Biofuel 1350⁺ KLPD
***GHG Savings** Potential > 1 MM Ton*

MSW generation in major Indian cities



Feedstock - STP Sludge, MSW Organics, Food waste, Industrial ETP sludge, Lignin
Products: Transportation fuel, Bio-char and Fertilizer-rich water

Feasibility Study → **First of it's kind commercial size plant** → Standardization of equipment/systems → Modular plants at strategic locations → **Global expansion multiple feedstock**

Tipping fee & Raw material agreements with municipal bodies

Policy Intervention For Biocrude Pricing

Product offtake agreements with Refineries

Partnerships
Waste management, Technology integration, Byproduct treatment

MARKET POTENTIAL

Biocrude → BioJet + *Other Transportation Fuels*

WORLD	**4-5 billion bbl**	**1.4 – 1.8 billion bbl** *60%-80% of World's ATF demand*
INDIA	**300-400 mllion bbl**	**100 – 140 million bbl** *More than India's ATF demand*

Economically superior technology for valorization of waste to biofuel/biochemcials

RCAT-HTL, for Advanced Liquid Biofuel

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Produces "Drop-in" liquid fuel. Can be processed in existing refining infra-structure

No additional Capex for refining, transport and distribution

Energy efficient process. **Water as reaction medium**. No need of drying wet waste.

> 85% reduction in GHG Emissions compared to fossil fuels

स्वच्छ भारत
एक कदम स्वच्छता की ओर

35+ patents/applications
AI based Kinetic Models

Feed-flexible process, making it sustainable technology.
RCAT-HTL is ready for commercialization

Golden Peacock 2018

Global Clean Energy Award 2018

Game Changer Award 2014

Thank You

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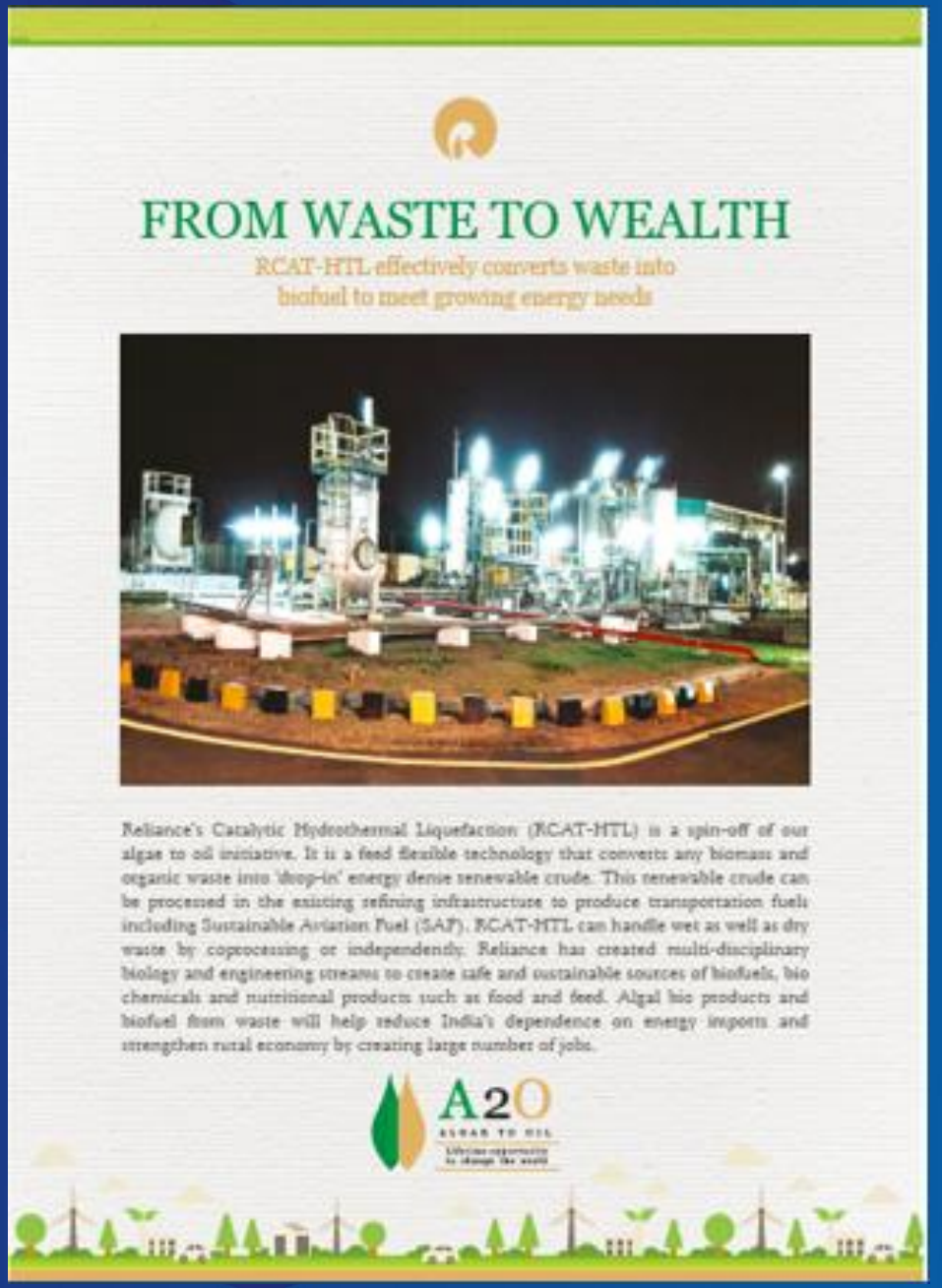

FROM WASTE TO WEALTH

RCAT-HTL effectively converts waste into biofuel to meet growing energy needs

Reliance's Catalytic Hydrothermal Liquefaction (RCAT-HTL) is a spin-off of our algae to oil initiative. It is a feed flexible technology that converts any biomass and organic waste into 'drop-in' energy dense renewable crude. This renewable crude can be processed in the existing refining infrastructure to produce transportation fuels including Sustainable Aviation Fuel (SAF). RCAT-HTL can handle wet as well as dry waste by coprocessing or independently. Reliance has created multi-disciplinary biology and engineering streams to create safe and sustainable sources of biofuels, bio chemicals and nutritional products such as food and feed. Algal bio products and biofuel from waste will help reduce India's dependence on energy imports and strengthen rural economy by creating large number of jobs.

A2O

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