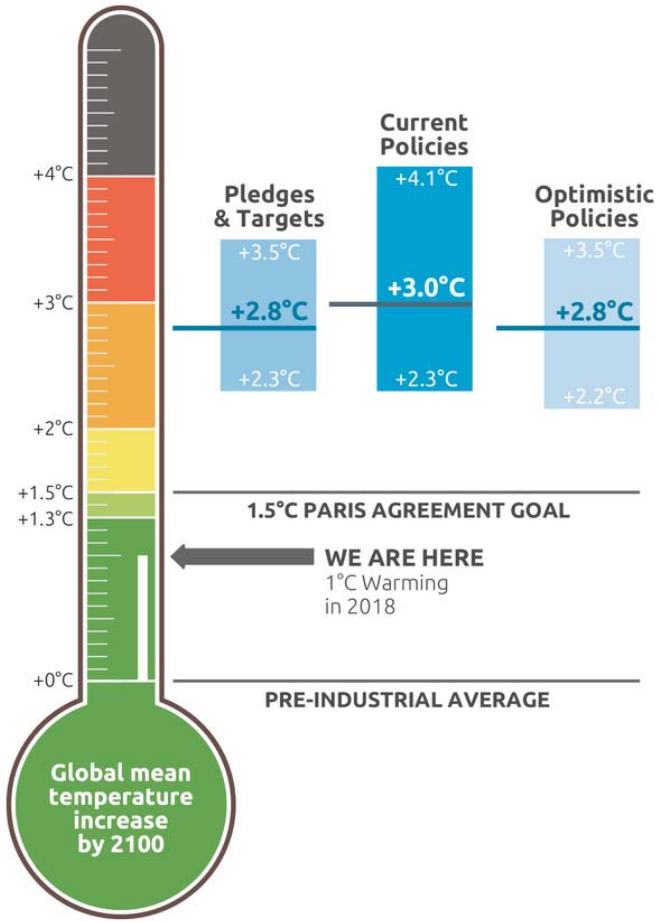
LanzaTech

Carbon Recycling

‘Innovating for a New Carbon Economy’

Presented by Dr. Preeti Jain, Director, LanzaTech

3rd EU-India Conference on Advanced Biofuels

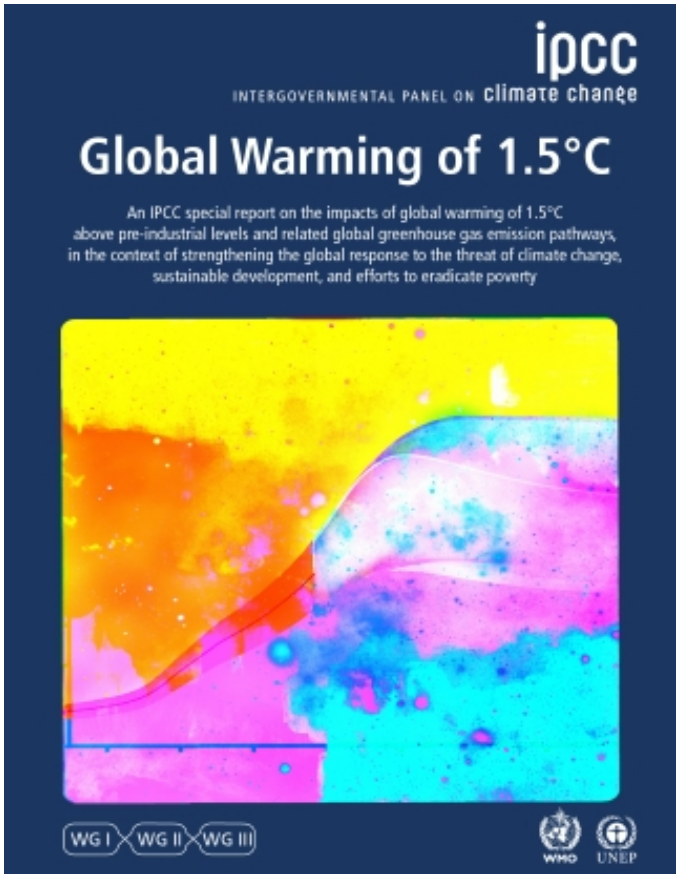


Climate Action Tracker

CAT warming projections

Global temperature increase by 2100

December 2019 Update



Paris Accord COP21
>90% Chance E*xceeding* 2°C

All 1.5°C Scenarios depend on Negative Emissions Technologies (NETs)

Energy can be carbon free

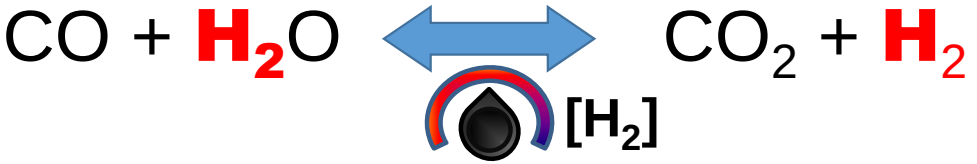
(Aviation) fuel needs carbon

Chemicals for everyday products need carbon

Recycling Carbon

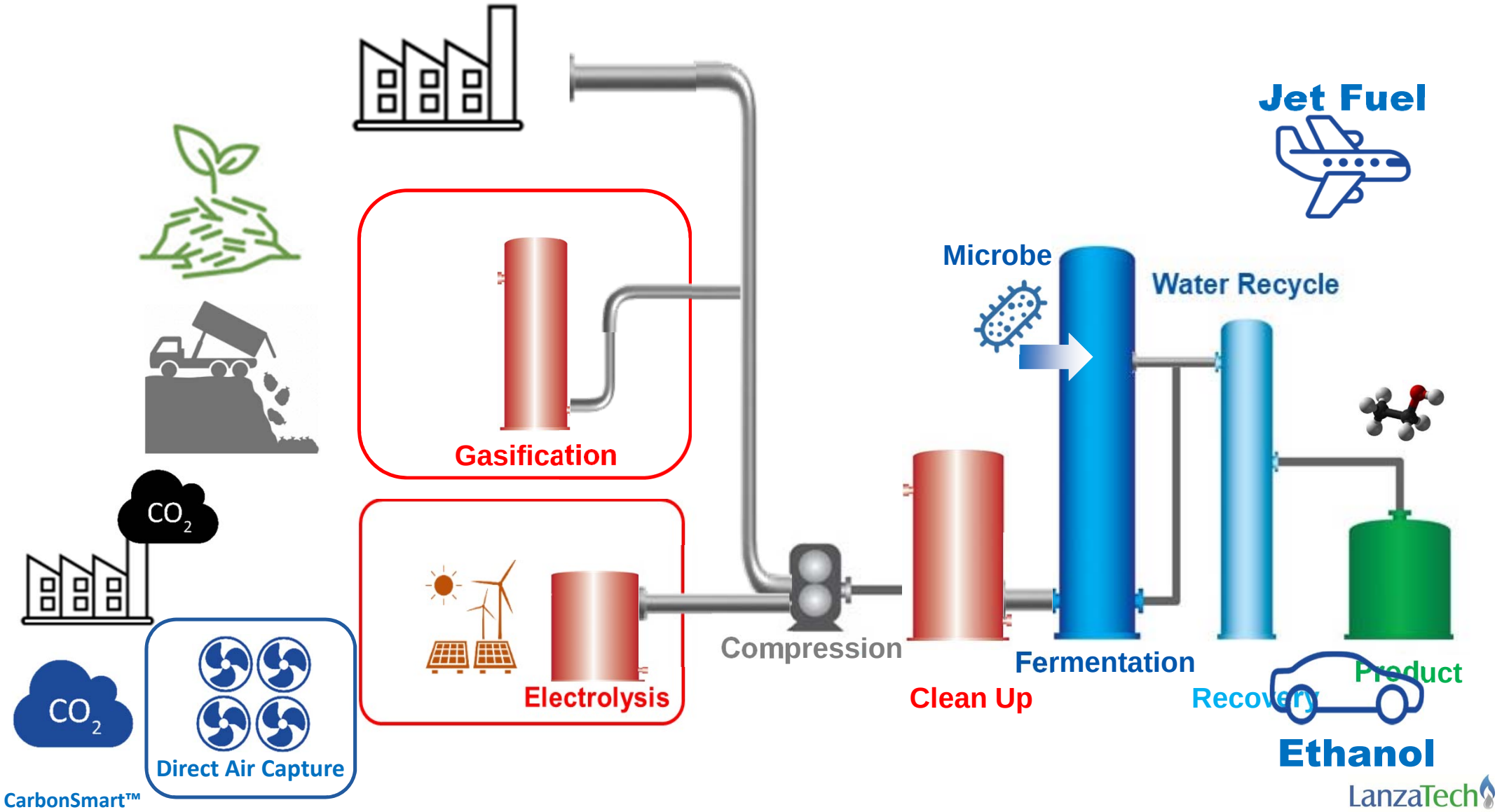
Industrial Off Gas
Biomass, MSW Syngas

A Bacteria Which Does Water Gas Shift…



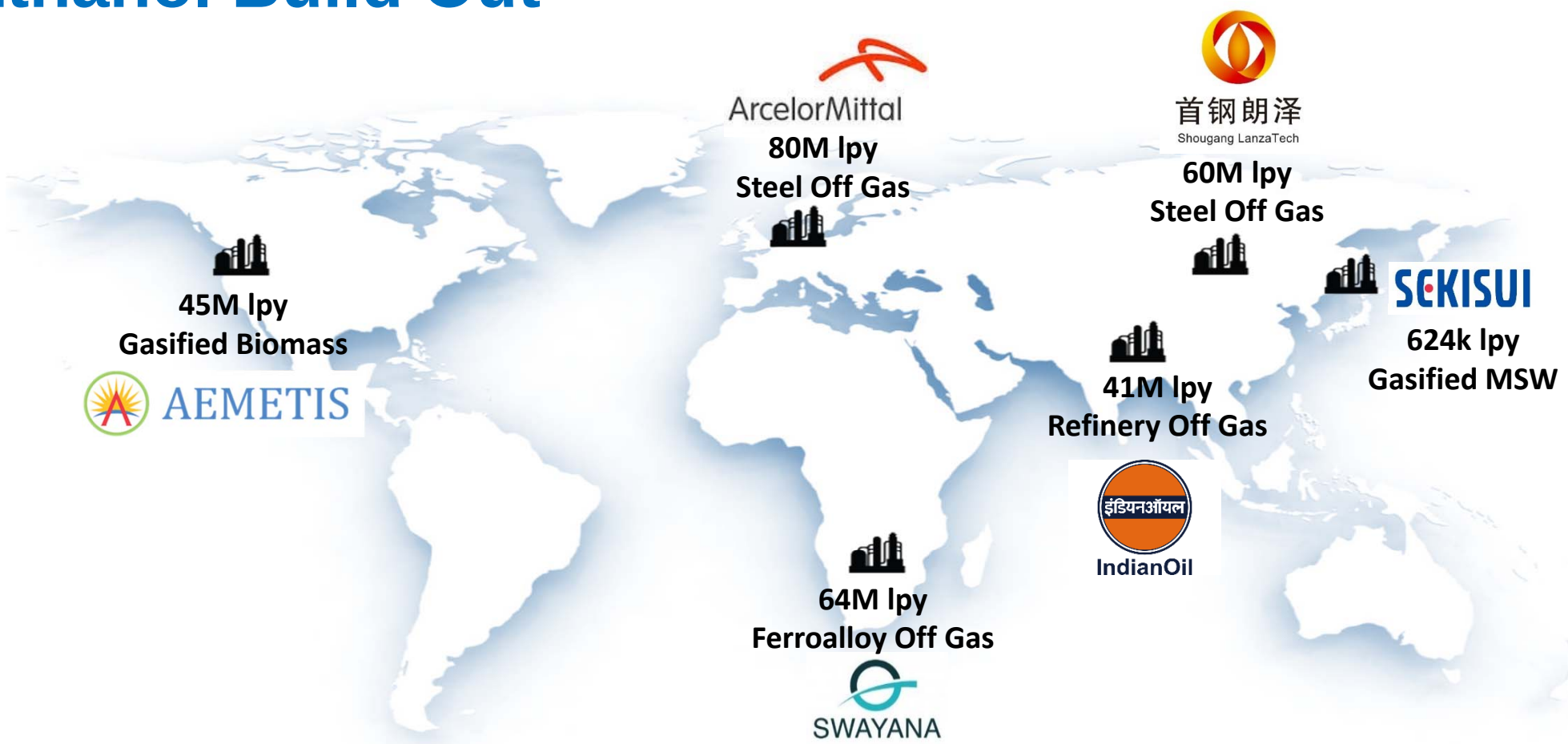
		H_2:CO Ratio		Carbon Efficiency	Energy Efficiency
CO	$6\ CO + 3\ H_2O \rightarrow \underline{EtOH} + 4\ CO_2$	0:1	**High CO off-gas (Steel Mills)** Commercial Unit	33.3%	↑
$CO + H_2$	$3\ H_2 + 3\ CO \rightarrow \underline{EtOH} + CO_2$	1:1	**Syngas (Biomass, MSW)** Demonstrated at scale	66.7%	80%
$CO + H_2$	$4\ H_2 + 2\ CO \rightarrow \underline{EtOH} + H_2O$	2:1		100%	
$CO + H_2 + CO_2$	$5\ H_2 + 1\ CO + 1\ CO_2 \rightarrow \underline{EtOH} + 2\ H_2O$	5:1	**High H_2 off-gas (Refinery)** Commercial in progress; CO_2 fixing in products	100%	↓

Carbon efficiency changes with different feedstock but energy efficiency remains relatively constant


Jet Fuel
Microbe
Water Recycle
Gasification
CO_2
CO_2
Direct Air Capture
CarbonSmart™
Electrolysis
Compression
Clean Up
Fermentation
Recovery
Product
Ethanol
LanzaTech

>45 Million Liters Ethanol Produced (China) Since Start Up

Ethanol Build Out



Accessing <u>all</u> global carbon waste ~2 Trillion liters ethanol

To Achieve Commercial Success it Takes…

Data

首钢朗泽
Shougang LanzaTech

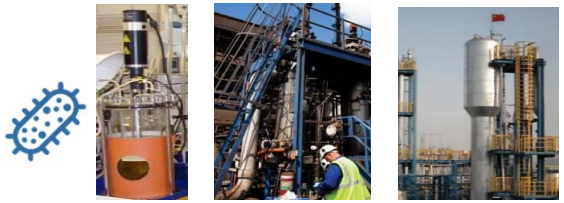
Multiple Demo plants at various scales

100,000 operating hours

Time

LanzaTech

CELEBRATING **15** YEARS



Lab Pilot Demo

Commercial

Money

>$340M

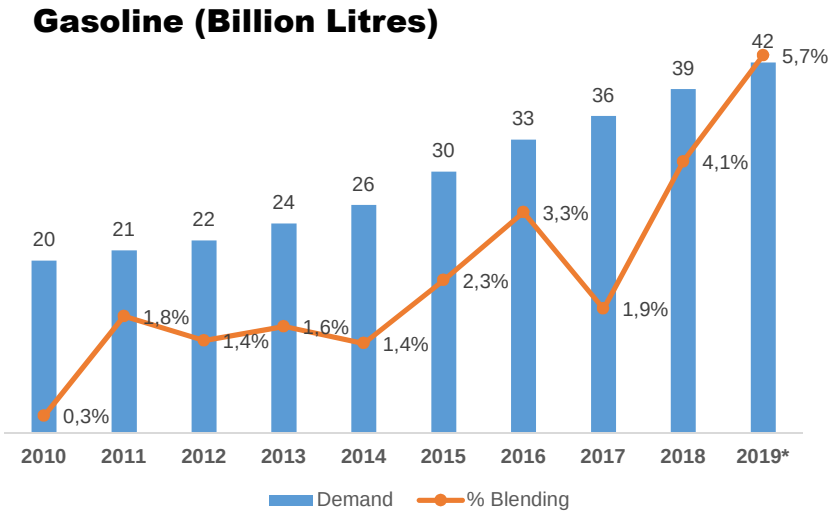
khosla ventures
novo holdings
Investors in life science
CICC 中国国际金融有限公司 CHINA INTERNATIONAL CAPITAL CORPORATION LIMITED
K1W1 K One W One Ltd.
MITSUI & CO.
IndianOil
QIMING VENTURE PARTNERS
NEW ZEALAND SUPERANNUATION FUND
BAOSTEEL
PETRONAS
PRIMETALS TECHNOLOGIES
BASF We create chemistry
CITIC CAPITAL 中信資本
XERAYA CAPITAL
SBCVC
SUNCOR ENERGY

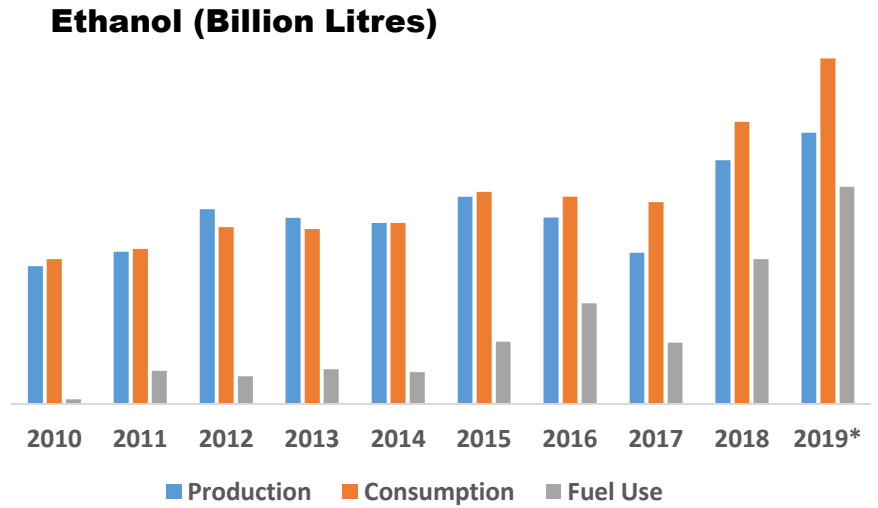
India

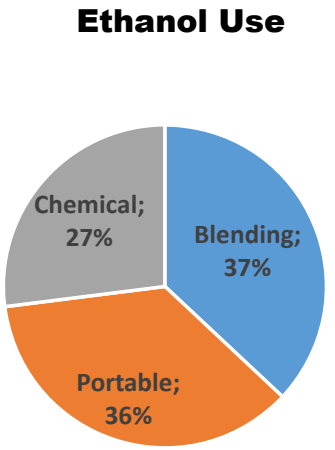
“Recycling Carbon for Local Impact”

India EtOH Market –Supply/Demand

- India's National Biofuels Policy (2018) directs E10 to reduce energy import; promote the use of environment-friendly fuel and boost the agriculture sector.
- With ambitious target of 20% ethanol blending by 2030, India Fuel ethanol demand increase many-fold.







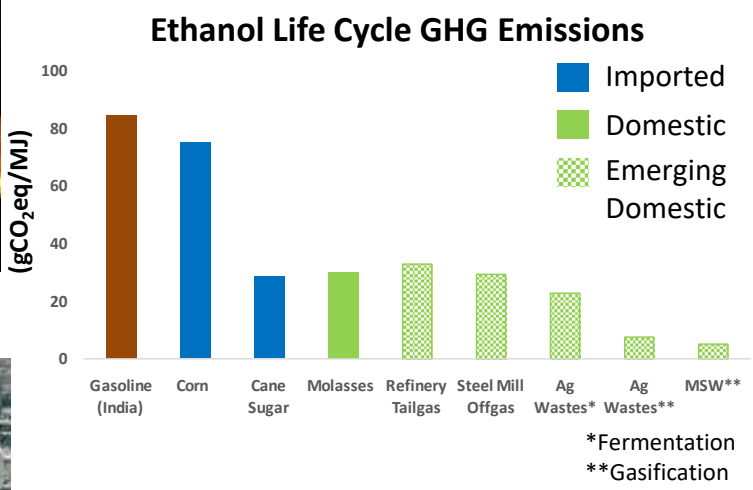
- Gasoline Consumption (2018-19): ~40B L; Ethanol (Domestic) for Fuel Blending available ~ 1.6B L
- **National Biofuels Policy(2018) dictates E10: ~4B L EtOH required**

Significant Supply/Demand Gap Expanding Domestic Sources Key

 Source: USDA, 2019, PIB

Harnessing India Waste Resource Potential

Domestic Resources for Low Carbon Ethanol



35Billion Litres/yr potential from wastes and residues

Significant Waste Resource Available for Biofuels Production

Carbon Recycling: Success Demonstration Ethanol from MSW (2013-2020)

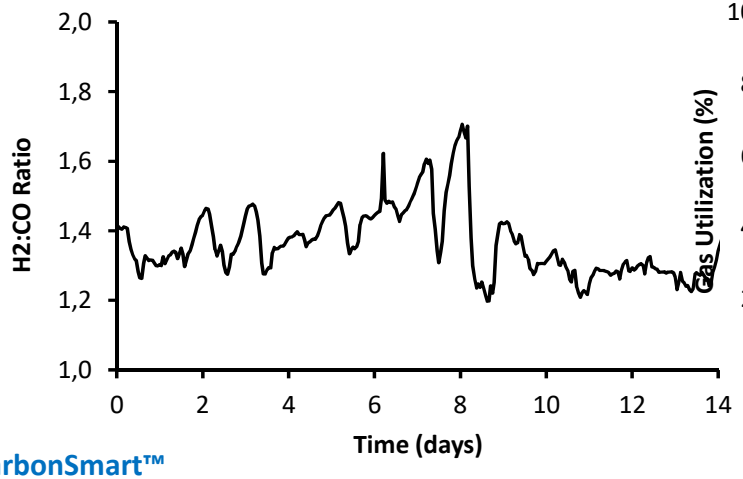
Unsorted MSW Feed

2013 Proof of concept

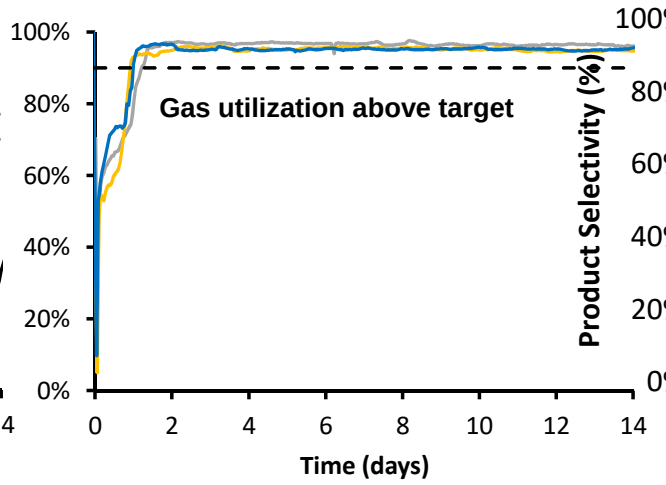
2014 (624k lpy) Pilot commissioned near Tokyo

➢ Slip stream of commercial, non-plasma gasifier operated to produce syngas for electricity production

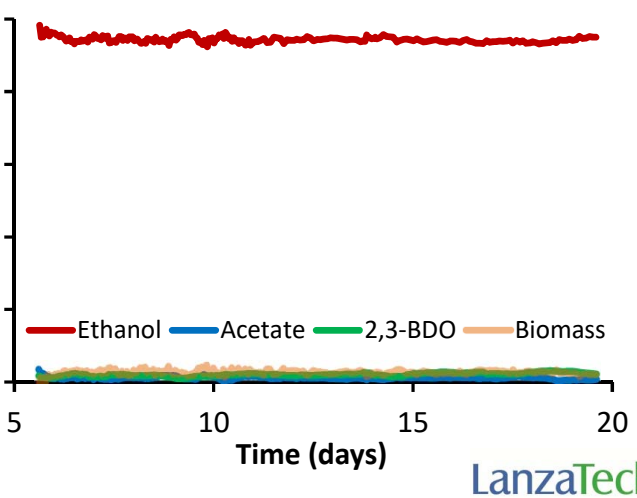
Robust Process in Face of Fluctuating Syngas



Consistent Ethanol Production Performance



Stable ethanol selectivity at 95%

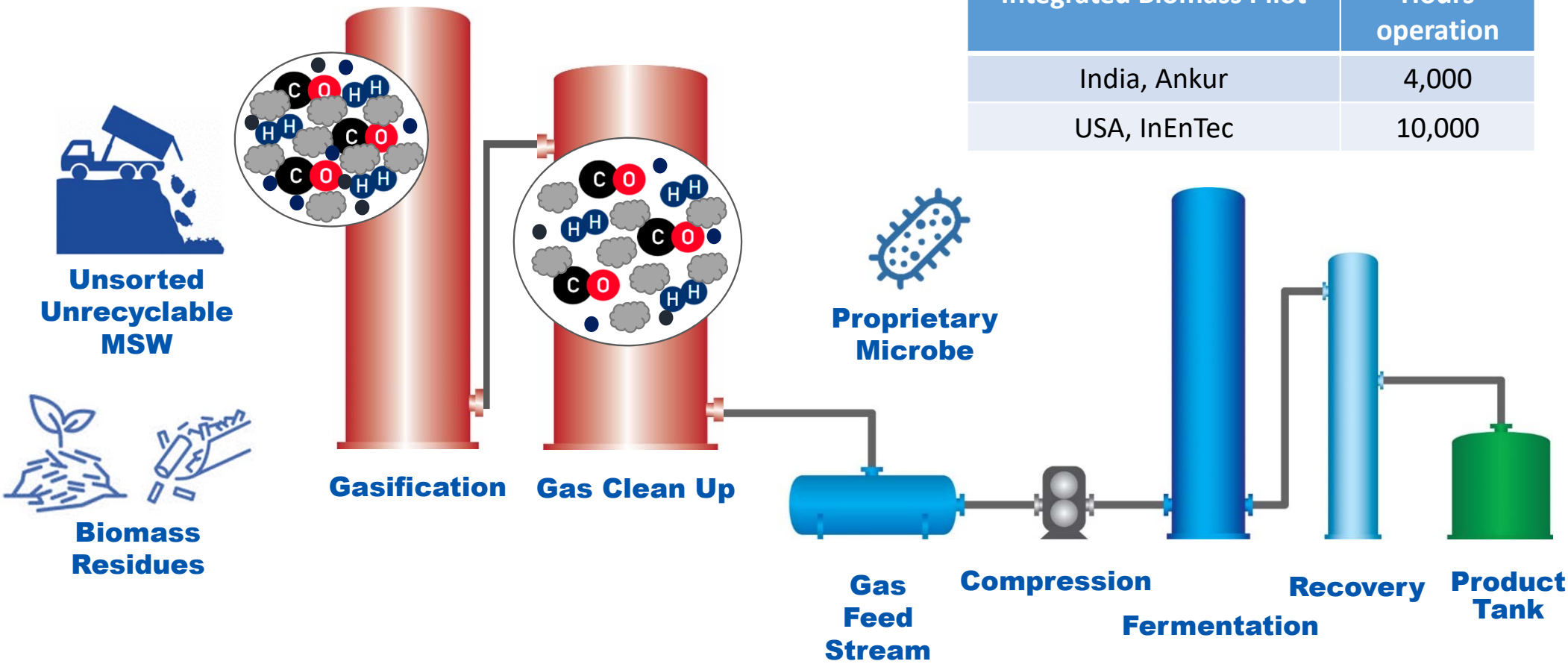


CarbonSmart™

LanzaTech

Gasification and Fermentation

Integrated Biomass Pilot	Hours operation
India, Ankur	4,000
USA, InEnTec	10,000



Variety of Feedstocks Successfully Demonstrated with Integrated Gasification Unit

Ethanol: Excellent Substrate
Building Block of the Future

RSB

首钢朗泽 Shougang LanzaTech

FEDERAL AVIATION ADMINISTRATION

BOEING

DARPA DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

HSBC

U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Pacific Northwest NATIONAL LABORATORY

virgin atlantic

SINOPEC

遠東新世紀 FAR EASTERN NEW CENTURY

INDIA GLYCOLS LIMITED

CarbonSmart™

LanzaTech

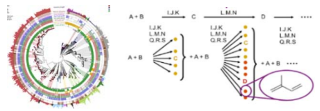
90B gpy by 2040

Need Volumes
Need Economic Solutions

State-Of-The-Art Synthetic Biology Platform

Discovery

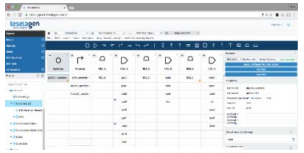
- *Sequence/Knowledgebase*
- *Retrobiosynthesis*



JGI · Northwestern Center for Synthetic Biology · U.S. Department of Energy

Computer-Aided Design

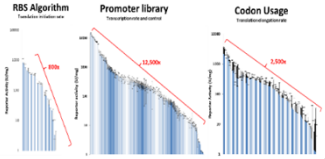
- *BioCAD*



teselagen BIOTECHNOLOGY

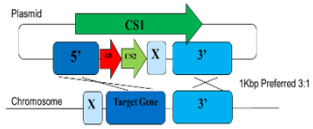
Genetic Parts

- *Reporters, Markers*
- *Promoters, Terminators*
- *RBS, Codon Usage algorithms*



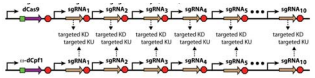
Genetic System

- *DNA transfer*
- *Modular plasmids*
- *Homologous recombination, CRISPR*



Advanced Toolbox

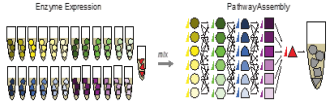
- *Multiplexing*
- *Genome-wide*
- *Genetic circuits*



PENNSTATE · U.S. Department of Energy

Rapid Prototyping

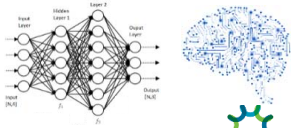
- *Cell-free protein synthesis*



Northwestern Center for Synthetic Biology · U.S. Department of Energy

AI

- *Machine Learning*



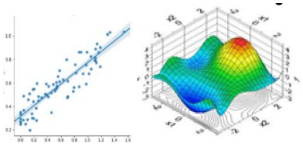
teselagen · Agile BioFoundry · Argonne National Laboratory · U.S. Department of Energy

10 years ago, gas-fermenting acetogens were considered genetically inaccessible

Today, a suite of tools across the development cycle have been developed

Modelling

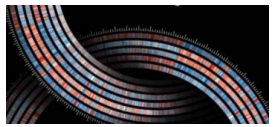
- *Genome-scale*
- *Kinetic*
- *Technoeconomic*



Northwestern Center for Synthetic Biology · U.S. Department of Energy

Systems Biology

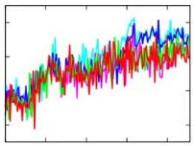
- *Multi-Omics*
- *Enzymology*



Oak Ridge National Laboratory · U.S. Department of Energy

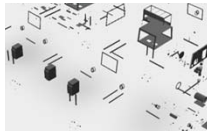
Automated Strain Evolution

- *Automated Strain Evolution*



Automated Strain Engineering

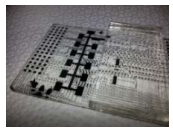
- *Anaerobic Biofoundry*



U.S. Department of Energy

Miniaturization

- *Microfluidics*



JBEI Joint BioEnergy Institute · U.S. Department of Energy

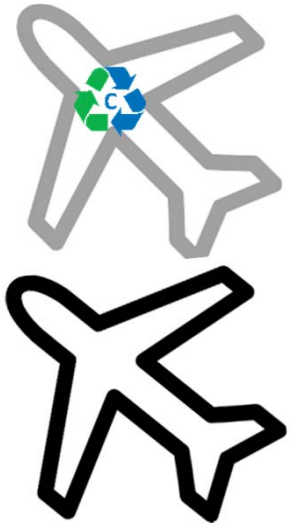
Direct Production of Chemicals from Recycled Carbon Pollution

MEG

Acetone

IPA

Direct Production Reduces Costs & Footprint



Consumer Choices Drive Change

Putting Carbon in the Circular Economy