Annexure - I
Presentations made by Experts

COAL-BIOMASS GASIFICATION IN OXY-BLOWN FLUIDIZED BED GASIFIER

Prakash Chavan

5th Jan, 2022

Virtual Meeting of Expert Committee for

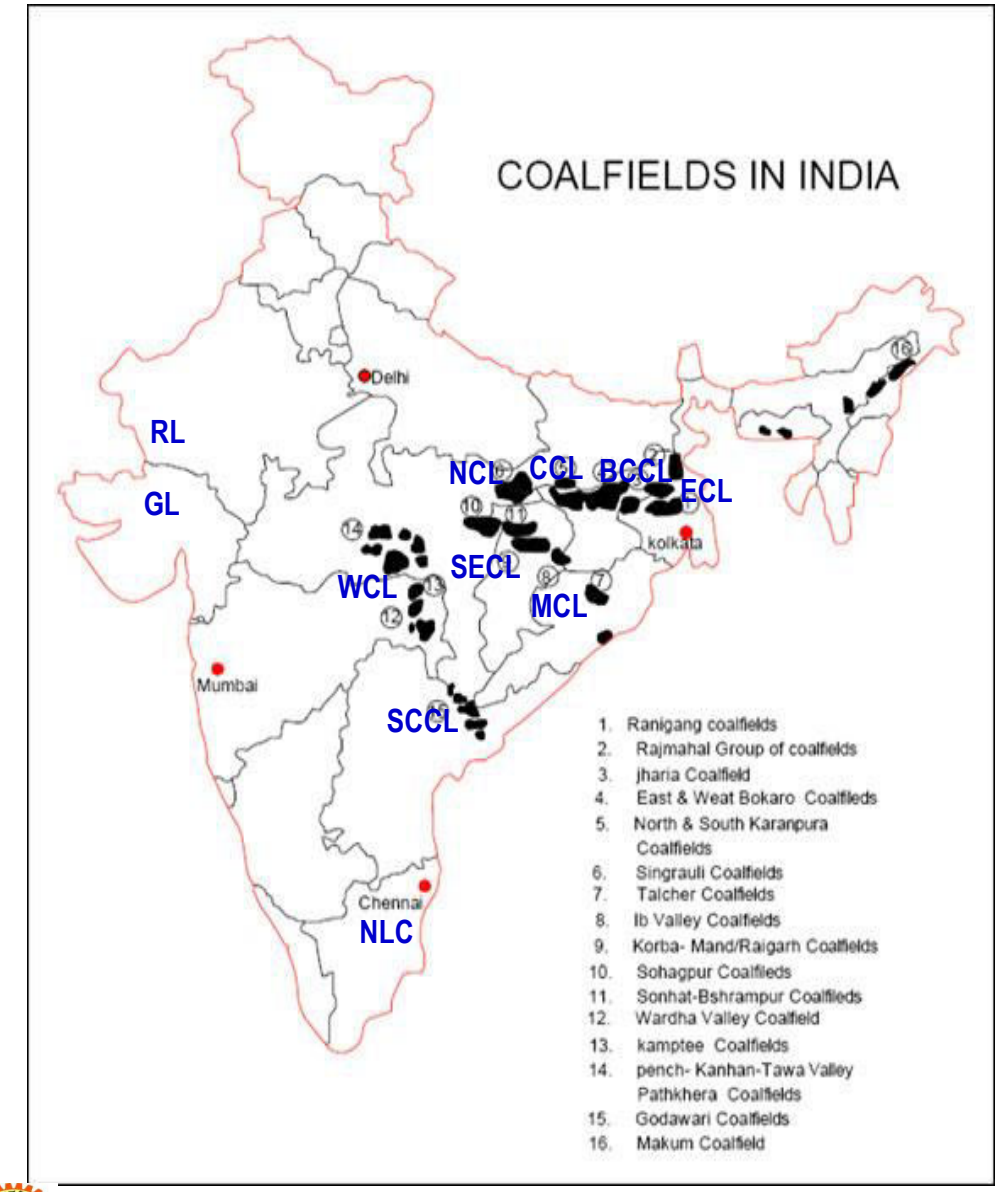
"Possible Technology Options for Conversion of Indian Coal to Hydrogen along with the CCUS Technology Options"

Gasification & Catalysis Research Group

CSIR-CENTRAL INSTITUTE OF MINING & FUEL RESEARCH

DHANBAD

INDIAN COAL SCENARIO



COAL & LIGNITE RESERVES IN INDIA

	Proved, BT	Indicated, BT	Inferred, BT	Total, BT
COAL	163.46 (47%)	150.39 (44%)	30.17 (9%)	344.02*
LIGNITE	6.79 (15%)	26.24 (57%)	12.99 (28%)	46.02

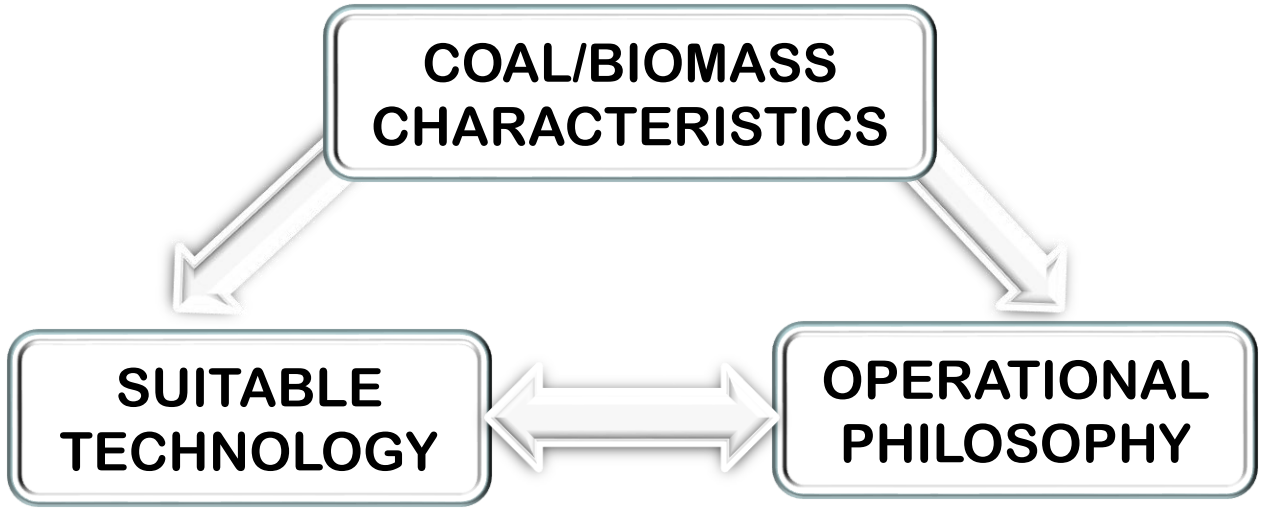
• Total estimated reserves of coal as on 1st April 2020, up to 1200 m of depth.
Source: Coal Directory of India 2019-2020 Coal statistics, GoI, MoC, CCO

COAL FIELD WISE COAL RESERVES

	Reserves Proved, BT	Coal with A+M <24, BT	Coal with A+M >24 & <34, BT	Coal with A+M >34, BT
ECL	22.4	2.37	8.83	**11.2**
MCL	40.9	0.45	1.60	**38.85**
CCL	16.8	0.74	4.13	**11.93**
SECL	27.2	2.10	4.95	**20.13**
WCL	9.4	0.66	4.42	**4.42**
NCL	13.1	0.85	5.31	**6.94**
Lignite	6.79	6.79	-	**-**
	Source: Coal Directory of India 2019-2020 Coal statistics, GoI, MoC, CCO Lignite ash content varies from 3 – 14%, Source: CSIR-CIMFR.			

For coal resource above 34% Ash + Moisture, suitable gasification technology is not available.

COAL GASIFICATION REQUIREMENTS



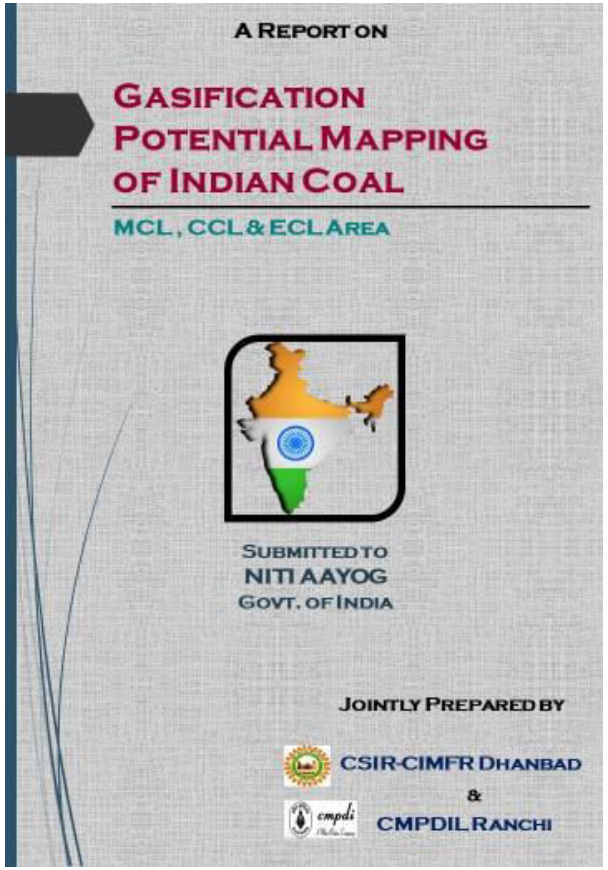
Understanding Solid Fuel Characteristics

Physico-chemical properties of fuel & Ash towards gasification.

Gasifier suitability vis-à-vis Utilization strategy

GASIFICATION POTENTIAL MAPPING

- NITI Aayog entrusted ***CSIR-CIMFR & CMPDIL*** **"Gasification Potential Mapping of Indian Coal"** (Notification: 17/05/2018)
- Completed mapping for **MCL** (13 mines, Ash: 20-46%), **CCL** (6 mines, Ash: 29-53%) and **ECL** (5 mines, Ash: 18-38%).
- Developed Coal characterization matrix for Physico-chemical properties of coal/Ash essential for gasification.
- Suggested ***Matching gasification technology*** vis-à-vis ***Utilization pattern*** & ***gasification strategy*** for gainful utilization of Indian coal resource.
- Report submitted to **NITI Aayog** on 24th Dec, 2019



Fuel choice may be the least flexible factor

due to economic, geographical and political reasons, so, it is necessary to adapt the gasification technology according to the available coal/biomass.

INDIAN COAL GASIFICATION STRATEGY: NITI AAYOG INITIATIVE

OPTION-1: COMMERCIALLY PROVEN GASIFIER
For Methanol/Fertilizer/DRI Plant

Entrained Flow Gasifier (Shell/Air Products)
with Low ash (<20%) coal & high ash coal after washing/blending with petcoke to reduce ash.

- Locations: Demo Plants of CIL at TFL, Talcher, WCL (Wardha), SECL (Mahamaya), ECL (Sonpur Bazari, Dankuni) Capacity: ~500 TPD Coal

Moving Bed Gasifier (Lurgi)
Low ash (<30%) coal & high ash coal washing or blending with imported coal

- Experience at JSPL, Angul (~3000 TPD Coal)

OPTION-2: INDIGENOUS GASIFIER
Retrofitting with Methanol Plants

PFBG PILOT SCALE PLANTS
CSIR-CIMFR, BHEL, IITD-Thermax & EIL
Proof of concept & Blueprint for Demo Plant

PFBG RETROFITTED DEMO PLANTS
300/500 TPD Coal, 2019-23
ECL, CCL, SECL, WCL
Outcome: DPR for 7500-25000TPD Plant

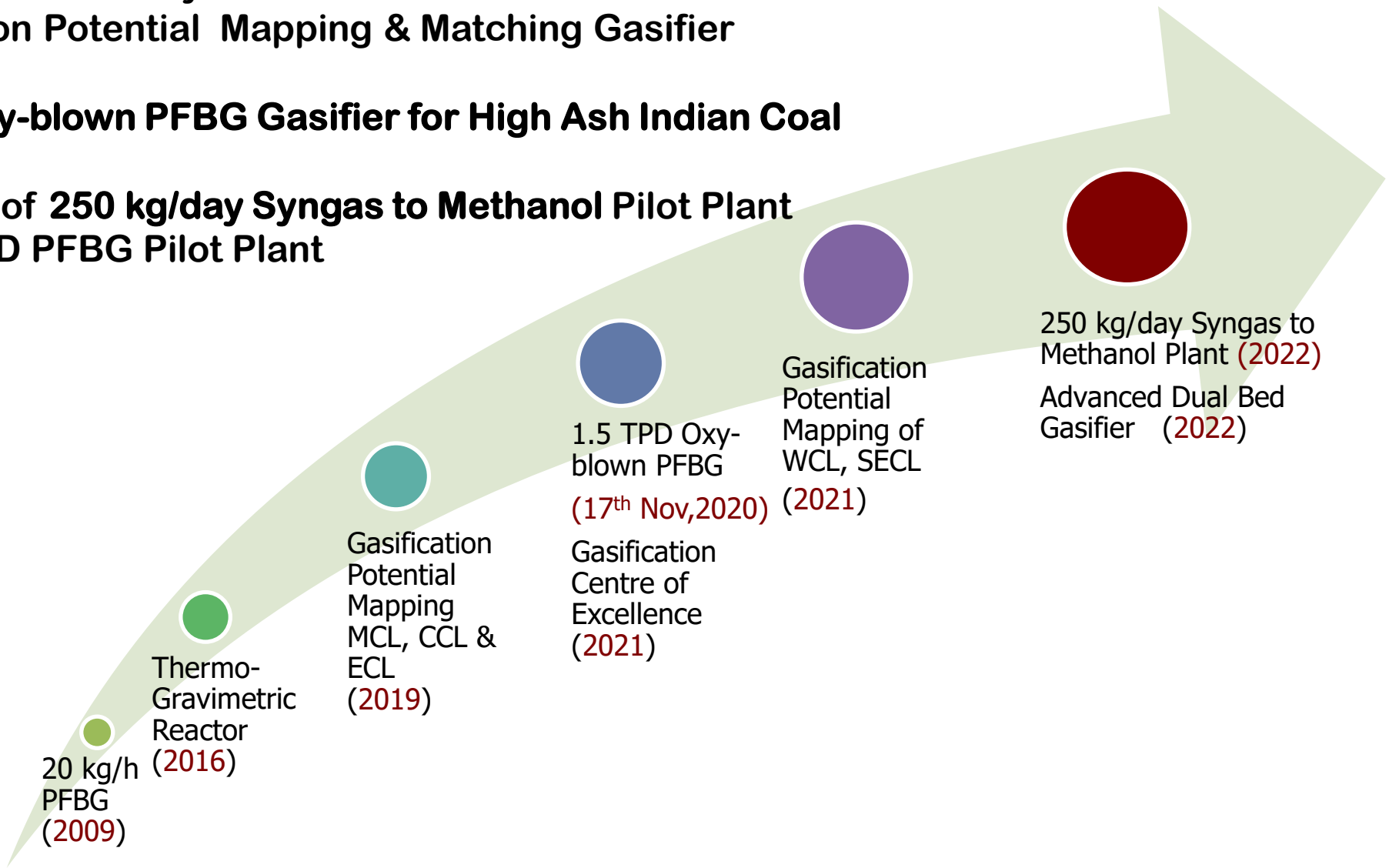
COMMERCIAL PLANTS
7500-25000 TPD Coal, 2023-30
Locations: Different Pit Head locations for utilization of 100 MMTPA coal for value added products

CSIR-CIMFR: Role in Indian Coal Gasification & Methanol Economy Program

- Member of NITI Aayog **Methanol Economy Task Forces**: (Notification Date: 23/05/2017)
- Member of **Technical Expert Committee** for **Talcher Fertilizer Limited** (TFL): (Notification Date: 14/06/2018).
- Member of **Technical Standing Group for Indian Coal Gasification Mission**: (Notification Date: 8/05/2020)
- **Nodal institution** for ***Resource Group for Gasification*** (Ministry of Coal): (Notification Date: 3/07/2020)

CSIR-CIMFR: Coal to Syngas & Methanol/Hydrogen Program

- **Gasification Centre of Excellence**
  - State of the Art Analytical Facilities & Pilot Plants
  - Gasification Potential Mapping & Matching Gasifier
- **1.5 TPD Oxy-blown PFBG Gasifier for High Ash Indian Coal**
- **Integration of 250 kg/day Syngas to Methanol Pilot Plant with 1.5 TPD PFBG Pilot Plant**



CSIR-CIMFR: Centre of Excellence for Gasification

❖ Bench Scale to Pilot Scale Gasification & Syngas utilization facilities.

- 20 kg/h Air-blown PFBG Pilot Plant
- 1.5 TPD Oxy-blown PFBG Pilot Plant
- Cold/Hot Fluidization study facilities
- Thermo-gravimetric Reactor
- High Pressure Micro Reactor for Syngas Processing
- Bench Scale High Pressure Reactor for Syngas Processing
- 250 kg/day Syngas to Methanol Pilot Plant (Ongoing)
- Advanced Dual Bed Gasifier (ADBG) for tar free syngas and C1, C2 gases (Ongoing)

❖ State of the art Analytical Hub for gasification and syngas utilization.

- Physico-chemical Characterization Facilities for Coal/Biomass, Ash, Syngas, Catalyst, etc
- Gasification Potential Mapping of Indian Coal/Biomass & Utilization Strategy.

❖ CFD Process Modeling & Simulation Laboratory.

❖ Gasification Training & Skill Development Centre.

- For Industry, Academic & R&D Institutions.

AIR BLOWN PRESSURIZED FLUIDIZED BED GASIFICATION FACILITY (TRL-5)

AIR BLOWN PFBG ACHIEVEMENTS

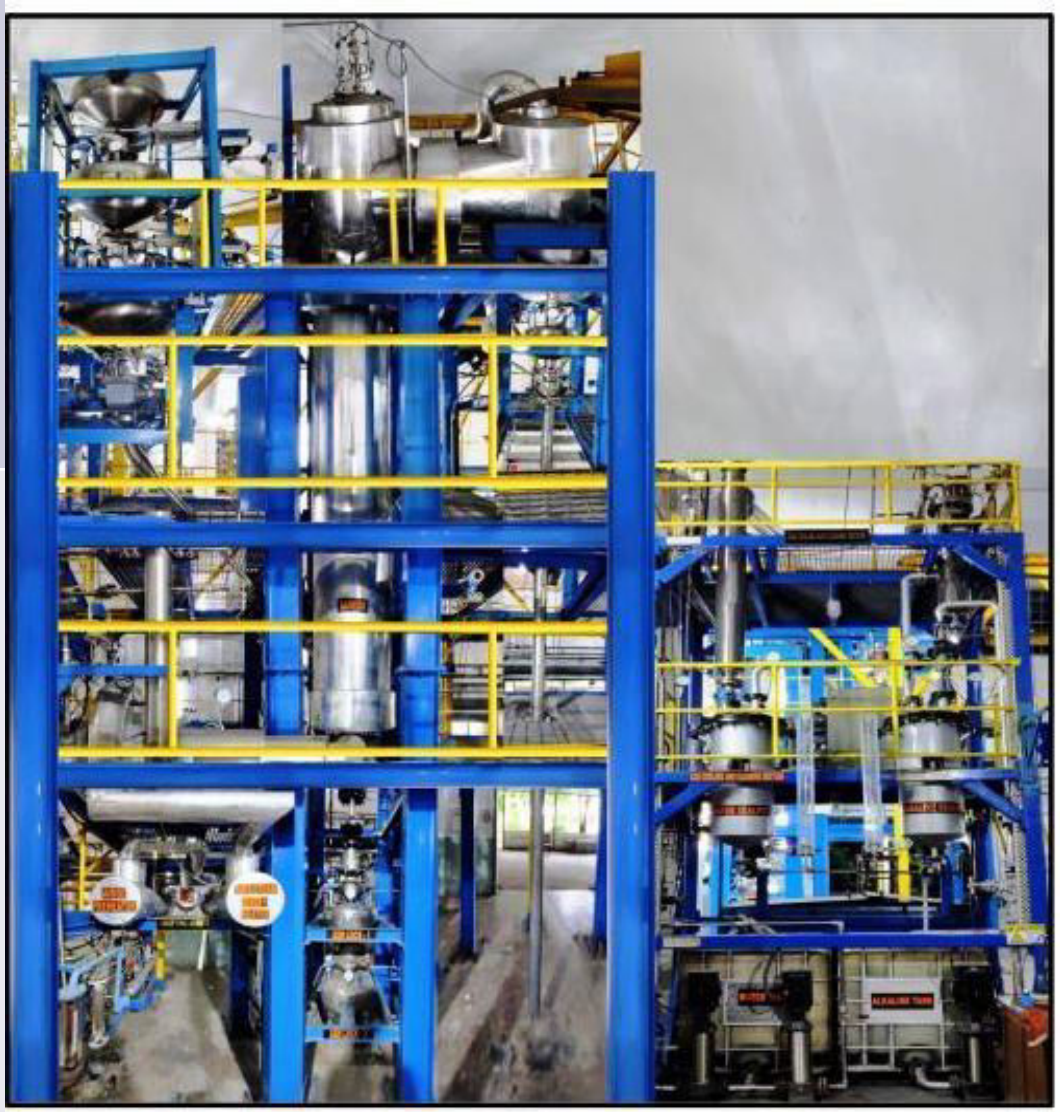
- Addressed operational issues: fuel feeding, ash agglomerates extraction
- Established operational philosophy for gasification in PFBG.
- Gasification performance of high ash coals, Biomasses & blends
- Design copyright & Indian Patent (TRL-5).

- Electrically heated alloy reactor (TRL-5)
- Installed in 2008-09
- Fuel Feed Rate : up to 20 kg/h
- Temperature: up to 1000 ^{o}C
- Pressure : up to 3 kg/cm^2

- Syngas Composition: (Vol.%)

  CO: 15-22, H_2: 15-20, CH_4: 1-2,CO_2: 10-12 & N_2
- Heat Value: 1000-1200 kcal/Nm^3
- Carbon Conversion : up to 93%
- Yield : 2.2-2.5 Nm^3/kg of fuel

1.5 TPD OXY-BLOWN PRESSURIZED FLUIDIZED BED GASIFICATION PILOT PLANT (TRL-6)



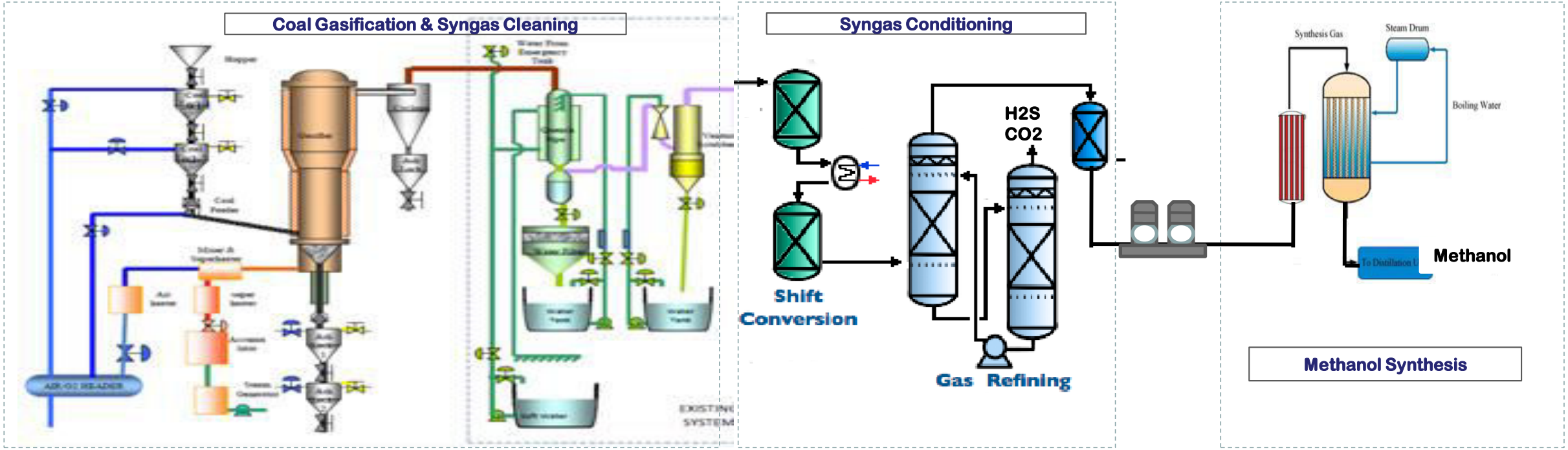
1.5 TPD PFBG PILOT PLANT

- CSIR-CIMFR design, Refractory Lined Gasifier
- Fuel Feed Rate : up to 1.5 TPD
- Gasifying Agents: Air/Oxygen & Steam
- Temperature: up to 1050 ^{o}C, Pressure : up to 10 kg/cm^2
- Facility dedicated to the nation on 17/11/2020

ACHIEVEMENTS:

- Oxy-blown Gasification of ***MCL, (Ash 42%) & MCL, (Ash 36%) with 92% Oxygen*** & Steam.
- Cumulative operation: >110 hrs.
- Syngas Comp. Vol.%: *CO: 25, H_2: 30, CH_4: 3.5, CO_2: 30,*
- Carbon Conversion: >95%,
- Syngas Yield: 1.43-1.68 Nm^3/kg fuel
- **Applied for Indian patent**

250 kg/day COAL SYNGAS TO METHANOL (CoSynol) PROGRAM (Ongoing….)



- Ongoing program is Mission Mode Activity under '**CSIR Mission Directorate**.
- Process will be established with commercial as well as indigenous catalyst from CSIR institutes
- Above facility can be utilized for Hydrogen generation from Coal/Biomass through gasification route
- Hydrogen % can be increased in the Shift Reactor from 30% to 45%
- CO_2 can be removed to desired level with Amine based scrubbing system from to get H_2 ~80 %
- Further, H_2 concentration can be increased to 98-99% by Membrane separation system.
- Expected H_2 generation ~55 g/kg fuel (0.6 Nm3/kg fuel) & CO_2 ~900 g/kg fuel (0.45 Nm3/kg fuel)

Water Gas Shift

- Developed Continuous Shift Reactor System
- Catalyst Capacity 500 ml
- Commercial Iron Chromium Based Catalyst
- Experiments Designed with Different Syngas Composition

BENCH SCALE WATER GAS SHIFT REACTOR

Syngas To Methanol

- Conducted Syngas to Methanol Conversion Experiments in 100 ml Bench Scale Reactor
- Used Cu-Zn-Al Based Commercial Catalyst
- Maintained Syngas Composition Expected at the Exit of WGS & CO_2 Scrubber (H_2: 58, CO: 32, CO_2:5.0 & CH_4: 5.0)
- Temperature: 200 -240 ^{O}C, Pressure: 40 – 70 kg/cm^2

SYNGAS TO METHANOL REACTOR

INDIAN COAL/BIOMASS RESOURCE: GASIFICATION STRATEGY

- **Understanding fuel:** Physico-chemical characterization of fuel for gasifier selection, Utilization pattern & Strategy (Washing/Blending & Co-gasification)
- ***Gasification potential Mapping & techno-economics*** of Indian Coal/Biomass Resource vis-à-vis ***utilization Strategy*** towards downstream applications.
- **Gasification Technology:** High temperature Entrained Flow Gasifier (Membrane wall) with washing/ blending or Oxy-blown Fluidized Bed Gasifier
- **Operational Philosophy:** AI based operational philosophy in relation with physico-chemical characterization of fuel for specific gasifier
- **Polygeneration:** Integration of Methanol/Chemical/Hydrogen generation with Fertilizer (Ammonia/Urea) as well as Power Modules to utilize side streams (N_2, CO_2, Heat)
- Exploitation of **Lignite reserves** and renewable resource biomass, RDF, Lignite
- Utilization of **membrane** based O_2 generation, selective separation of H_2, CO_2
- **Collaboration with Engineering Houses for Upscaling of the Pilot Plant to Demo Scale**

SUMMARY

Indigenously developed **1.5 TPD PFBG** Facility (TRL-6) is a milestone achievement as a part of "Methanol Economy Program" and an important step towards ***"Atmanirbhar Bharat Abhiyan"*** of Govt. of India.

Outcome:

- Engineering inputs for the ***development of Demo Scale PFBG*** suitable for Indian High Ash Coal/Biomass resource.
- ***Gasification potential*** of high ash Indian coal ***& techno-economics*** vis-à-vis ***utilization prospects*** for downstream applications such as Methanol/chemicals, hydrogen, fertilizers, DRI.
- Integration of Syngas micro-cleaning, conditioning and 250 kg/day ***Syngas to Methanol Pilot Plant*** with 1.5 TPD PFBG Pilot Plant.
- ***CSIR-CIMFR may act as an indigenous technology developer, Resource Centre and knowledge partner*** in the Coal Gasification initiatives of the Govt. of India.

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Membrane-based Separation of Hydrogen from Coal Derived Syngas: A Near-term opportunity for Scale-up and Commercialization

Virtual Meeting on

CONVERSION OF INDIAN COAL TO HYDROGEN ALONG WITH THE CCUS TECHNOLOGY OPTIONS

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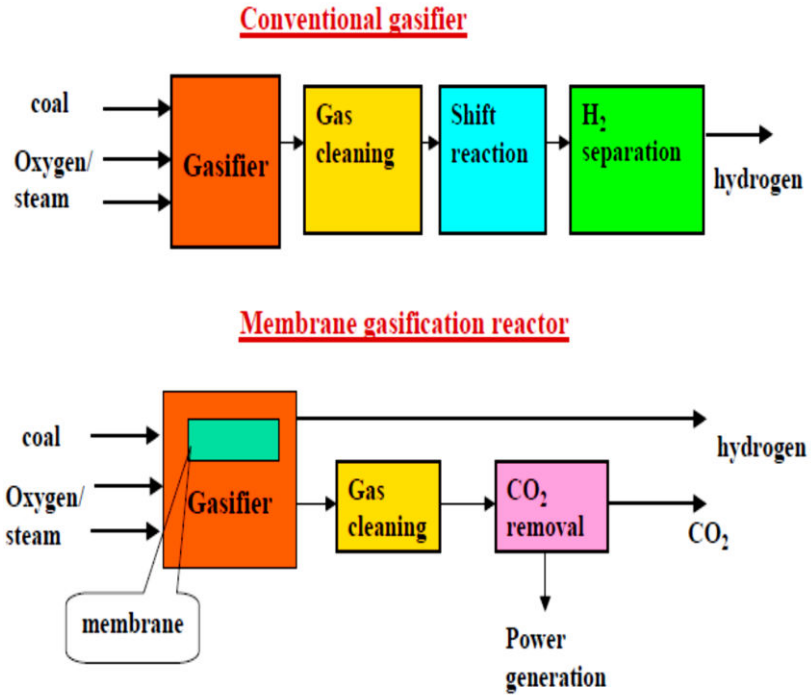
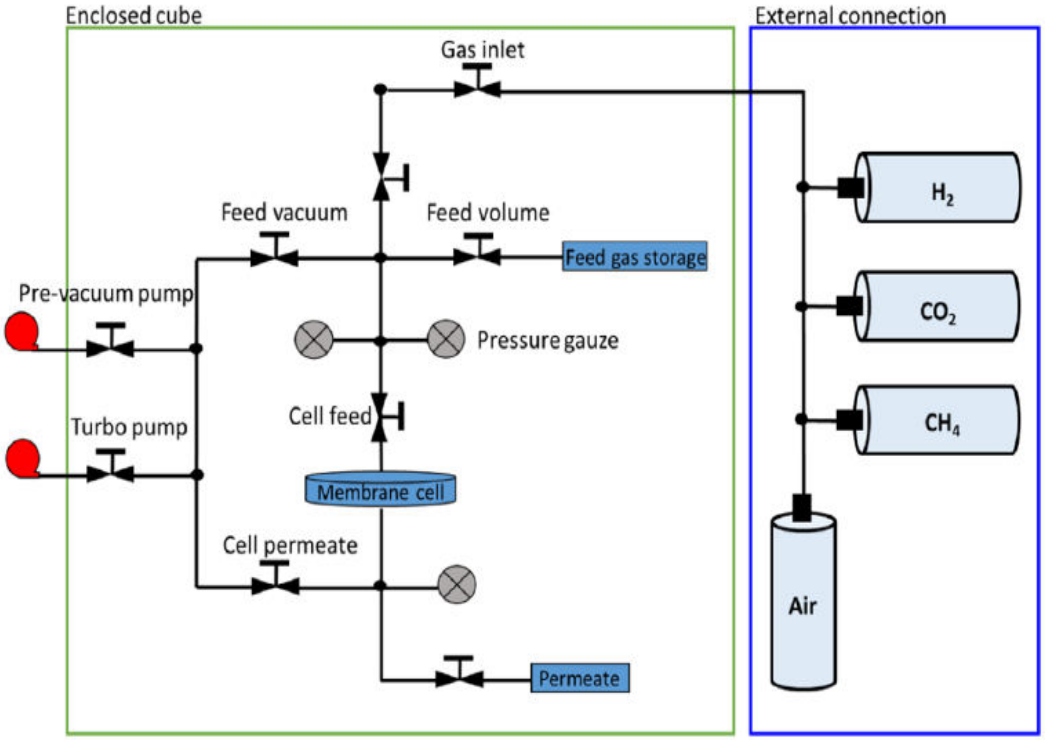
Conceptualization

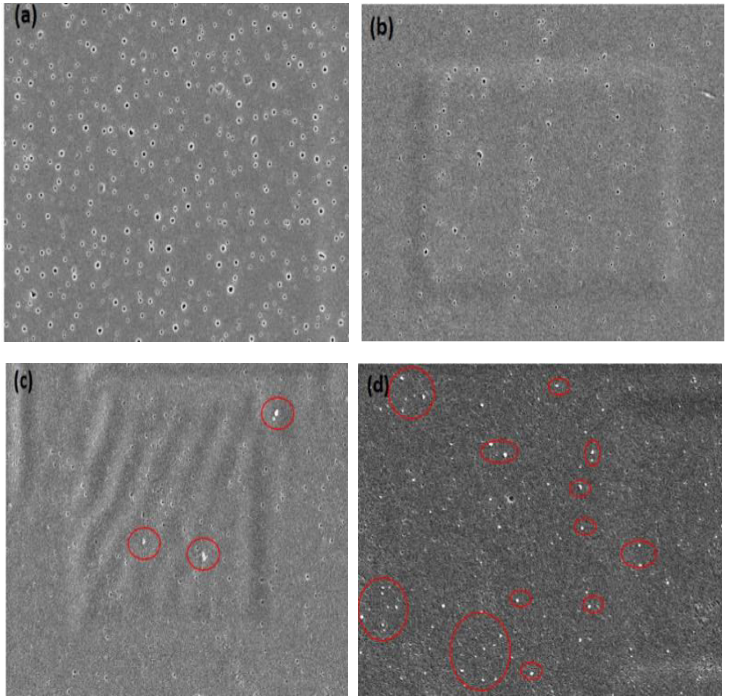
- H_2 is 14 times lighter than air.
- Mass basis - High energy content of 120 MJ/kg.
- Volumetric basis – Energy content is 10.8 (MJ/m^3).

- Membrane-based H_2 separation – fast chemical kinetics and good WGS equilibrium.
- Dense polymer, microporous ceramic, porous carbon, dense metallic, and dense ceramic.
- Operational temp, selectivity, and flux
- Can produce hydrogen - 99.99 % purity
- Dense metallic – T=300-600 °C, P=up to 35 bar



Current State of Work





fabricated membranes	membrane thickness (μm)	tensile strength (MPa)	% elongation	tensile modulus (MPa)
CA	33	48.712	7.82	1010.825
0.5% $(PdOAc)_2$/CA	27	50.261	8.74	1059.37
0.75% $(PdOAc)_2$/CA	27	62.857	12.06	882.096
1% $(PdOAc)_2$/CA	28	55.18	7.56	1400.972

Gas supply pressure = 2 bar

Temperature = ~RT (25 ^{o}C)

Downstream Pressure = ~10^{-5} atm

Road Map for Scale Up

Membrane Material Development

- Material Synthesis
- Screening and Testing
- Contaminant Issues
- Stability and Durability

Membrane Module Development

- Design of Membrane Gasifier Configuration
- Large-Scale Membrane manufacturing

Membrane Process Development

- Flow sheet development and Simulation
- Optimize operation conditions
- Economic analysis

Membrane Gasifier Scale-up

- Engineering Design
- Pilot Scale
- Demonstration

Cost Benefit Analysis

- It is estimated that Hydrogen produced by coal gasification with CCUS may vary from \$1.6/kg H_2 to around \$2.1/kg H_2.
- Capital expenditure (Capex) and Operating costs (Opex) account for around 80%-85% of the cost.
- Fuel accounts for the remaining 15%-20%.
- The addition of the CCUS system contributes to around a 5% increase in Capex.

Thanks a lot!

Thermax Experience on

- Coal to Chemicals
- Coal to Hydrogen
- Carbon capture and utilization

Thermax at a Glance

Conserving Resources.
Preserving the Future.

822
MILLION USD COMPANY

RANGE OF ENGINEERING SOLUTIONS

HEADQUARTERED IN
PUNE, INDIA

27 GLOBAL NETWORK IN COUNTRIES

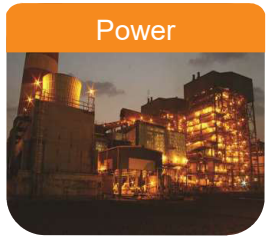
14 MANUFACTURING FACILITIES

10 IN INDIA, 4 GLOBAL

INSTALLATIONS IN
88 COUNTRIES

30 SUBSIDIARIES

Thermax Portfolio



Utilities

Raw Material

Desired Products

Waste

Research Technology & Innovation Centre (RTIC)

Strength : 147
PG / PhD's: 61+6
Fellowships: 13

300+ Total Patents*

Total Trademark Registered **200+**

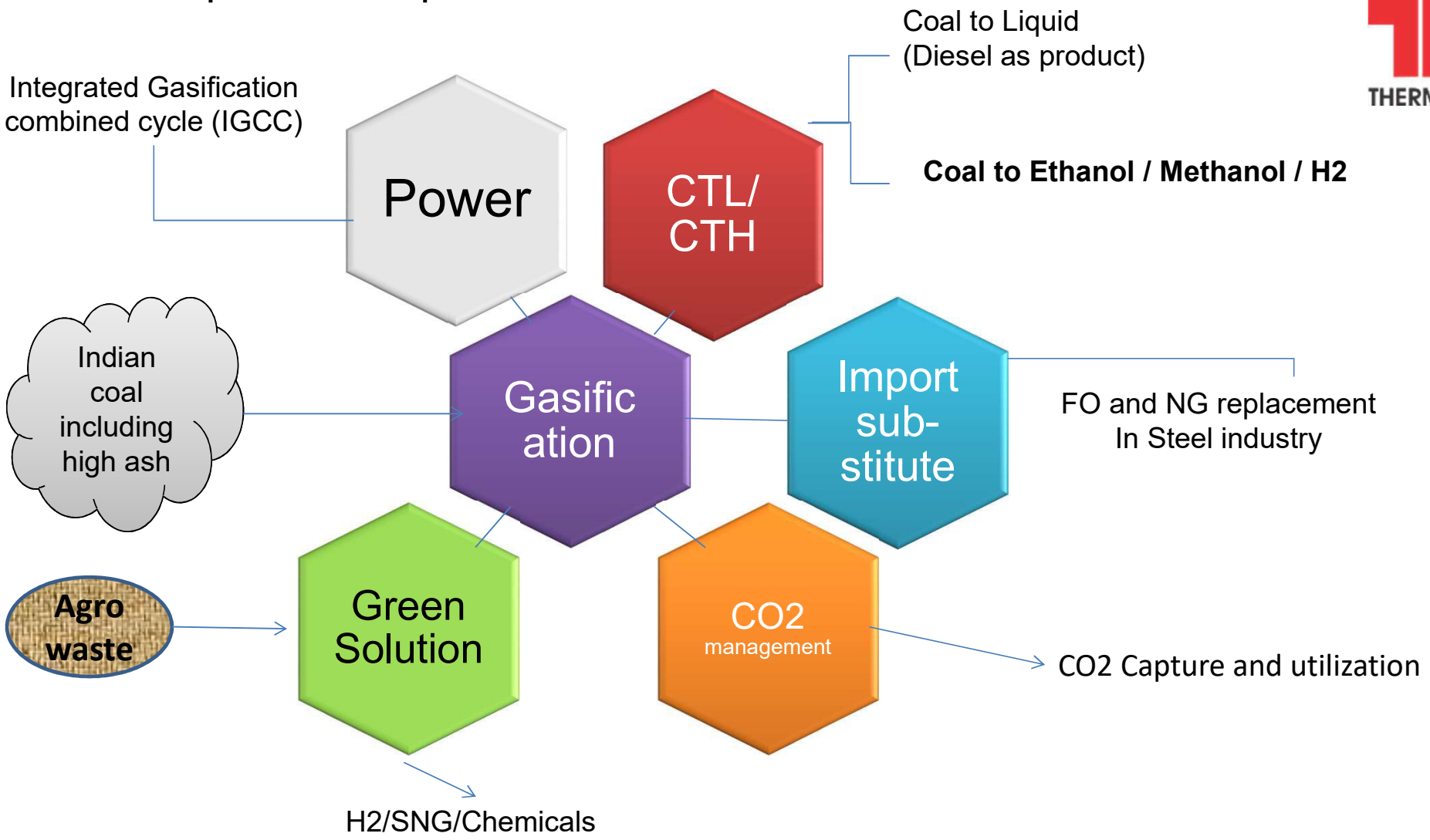
Centers of Excellences:

- Combustion & Gasification
- Biotechnology
- Material Science
- Process Design, Controls, System Integration

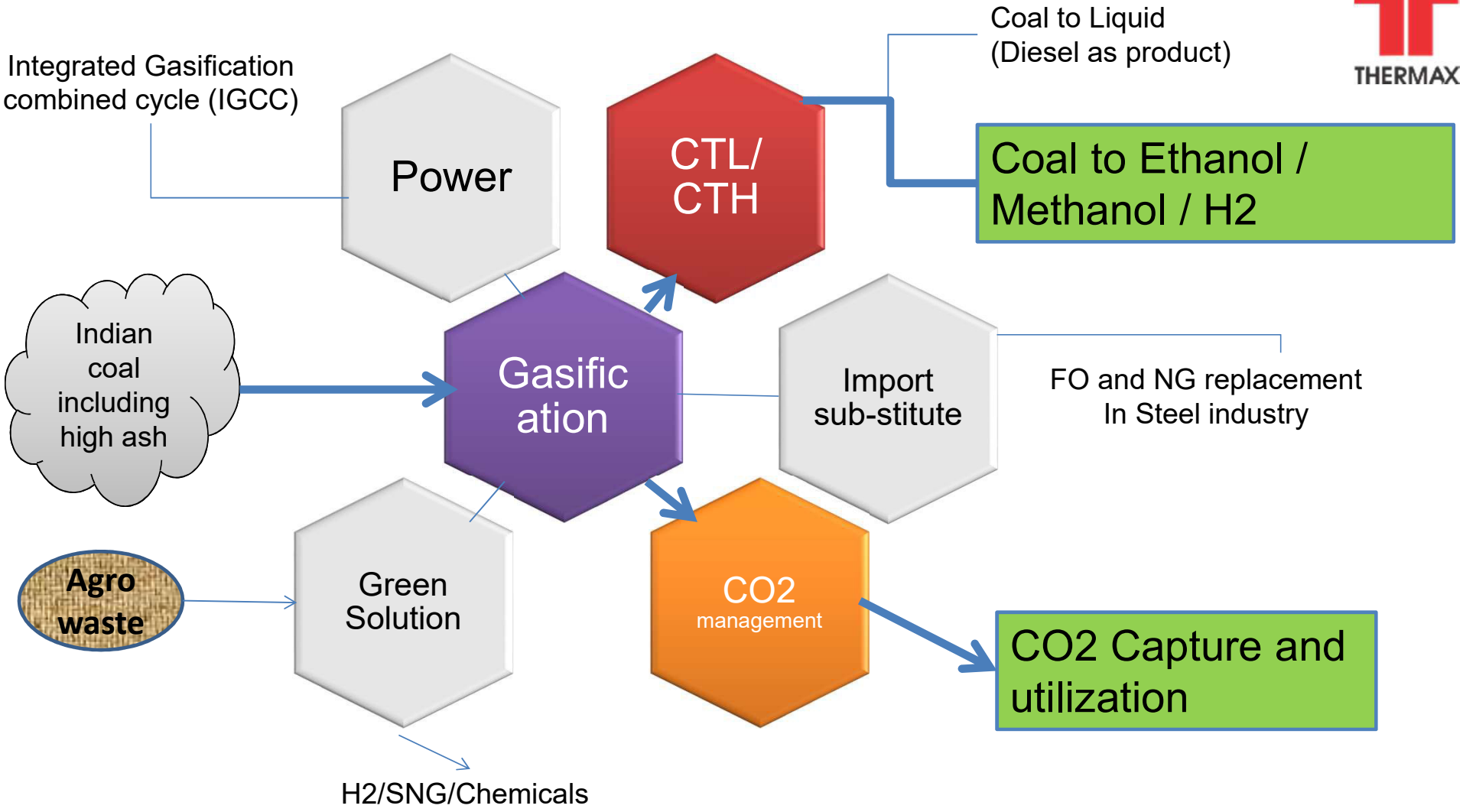
*Including filed patents

Thermax Foray Into Coal Gasification

Gasification platform capabilities:



Gasification platform capabilities:



Thermax Gasification Technology Development Journey:-

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Conceptualization

Award of 1MWe Coal gasifier for IGCC & CTL

Award of EIL & Indo-EU project

DRDO Multi feed Gasification studies

Award of 4.5 MW Biomass Gasifier SYNOVA-ECN

2011

2013

Commissioning of 250 kW

Commissioning of EIL

2015

Commiss. of 1 MWe

2016

Demo of 20 kW synGas engine

Commiss. of 4.5 MW Biomass Plant

2017

Demonstration

1 TPD Coal to Methanol project – DST-IITD program

2019

Commissioning of 1TPD plant

2022

Propose DPR for a 300 TPD plant

Drivers for Clean coal power & synfuels

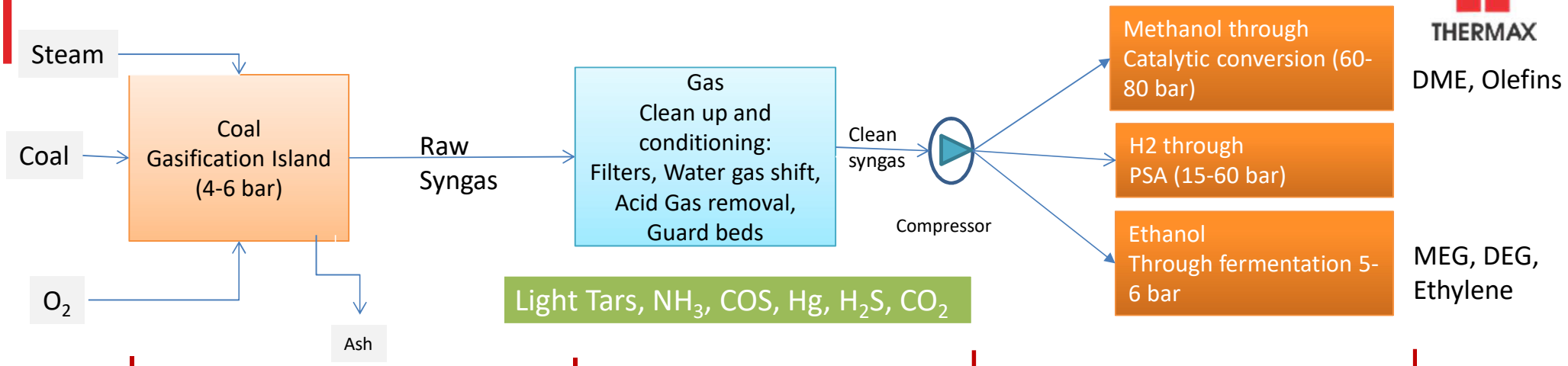
Collaborators

ECN, EIL, Bharat Petroleum, cnrs, DAHLMAN

On going Project/Studies:

1. Coal to Methanol (DST Project
2. Coal to Ethanol
3. BioCNG from Agro waste (Under execution)
4. Coal to H2 (Exploratory)
5. Flue gas CO2 utilization to methanol (Exploratory

Technology blocks for Coal to Chemicals , Fuel and H2



1) Oxy blown gasification tested
2) Gasifier, candle filter, feeding system installed

Target Parameters:
- H2/CO >1
- N2< 2% v/v
- S/C < 1.3
- O/C <0.5

1) Particulate : Ceramic filter
2) Tar : Oil based system
3) Shift: Sour WGS
4) H2S + CO2: Amine
5) Minor impurity: Guard beds

Target Parameters:
- COS, H2S <1 ppmv
- NH3, HCN < 10 ppmv
- CO2 < as required
- H2/CO ~as required

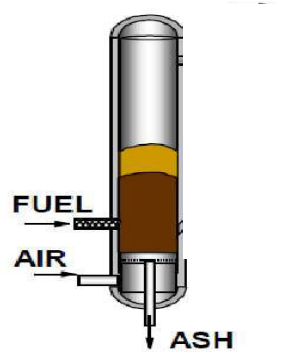
1) compressor : main and recycle
2) Catalyst
3) Enzymes

Target Parameters:
- COS, H2S <0.1 ppmv

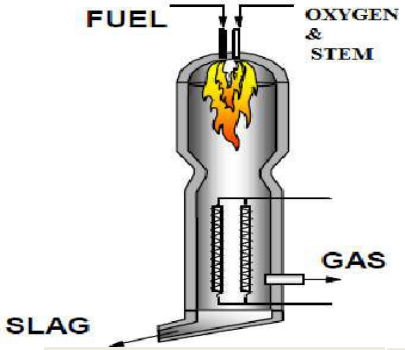
Comparison of Coal Gasification Technologies

THERMAX

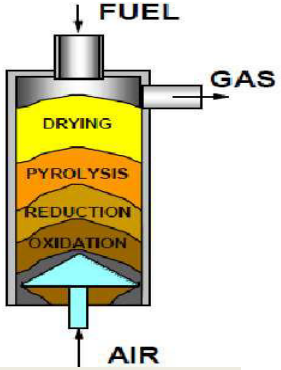
Types of gasifier



Fluidized



Entrained flow



Updraft moving bed

Parameters	Fluidized bed	Entrained Flow	Moving bed
Max. ash in coal (wt.%)	25 - 42%	<20%	<30%
Suitability to India's high ash coal	Suitable	No standalone installation worldwide	Suitable only for freshly mined coal
Reliability (Life of refractory)	High	Low (abrasive ash)	Low
Slag formation	NO	Yes	Yes
Coal	<6mm	pulverized	Sized 25-50 mm
Heavy Tars Issue	No	No	Yes (severe)

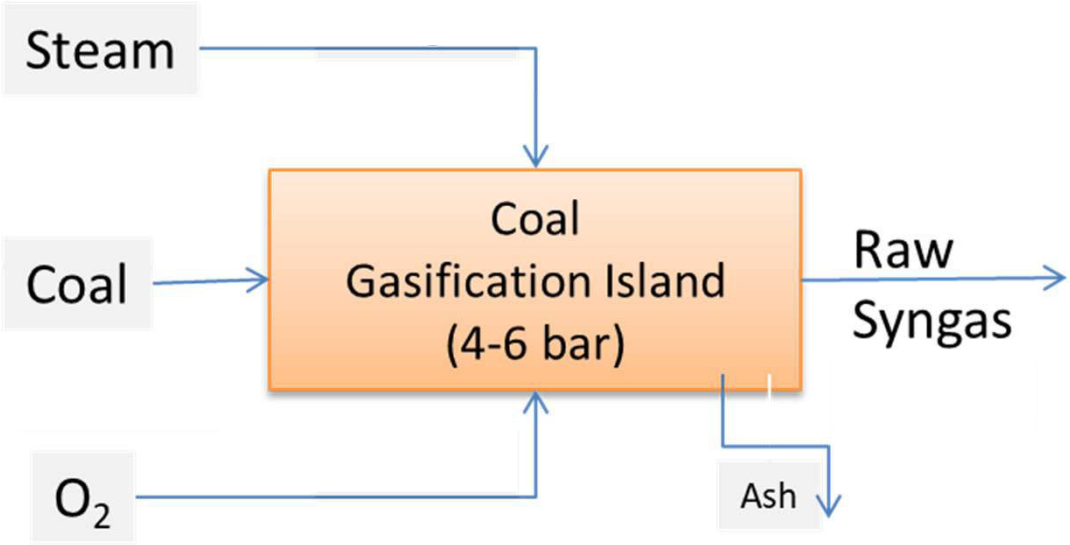
Advantages of FBG

- High ash coal is reactive fuel
- High Initial deformation temperature (>1200°C) allows gasifier to operate ~1000°C for providing better efficiency
- Low velocity (<1.5m/s) in FBG aids handling of abrasive ash (quartz content)
- 30% Less oxygen consumption due to 900 - 1000oC temperature operation
- Indigenous components leading to lower CAPEX of plant for high ash coal
- Integrated Fluid bed char combustor for best overall efficiency

Fluidized Bed Gasification (FBG) Suitable for Mid / High Ash Coal

THERMAX

Developed knowhow



1) **Bubbling Fluidized Bed**
2) **Oxy blown**
3) **Fire side pressurised (upto 6bar)**
4) **Control of C/Steam Ratio**
5) **Heat recovery unit for syngas heat**

Coal to Methanol – Technology demonstration Plant

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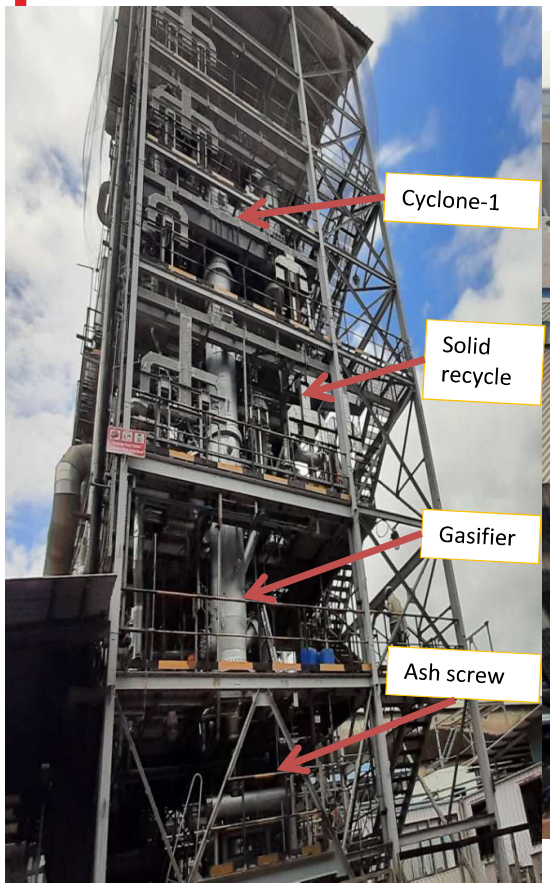
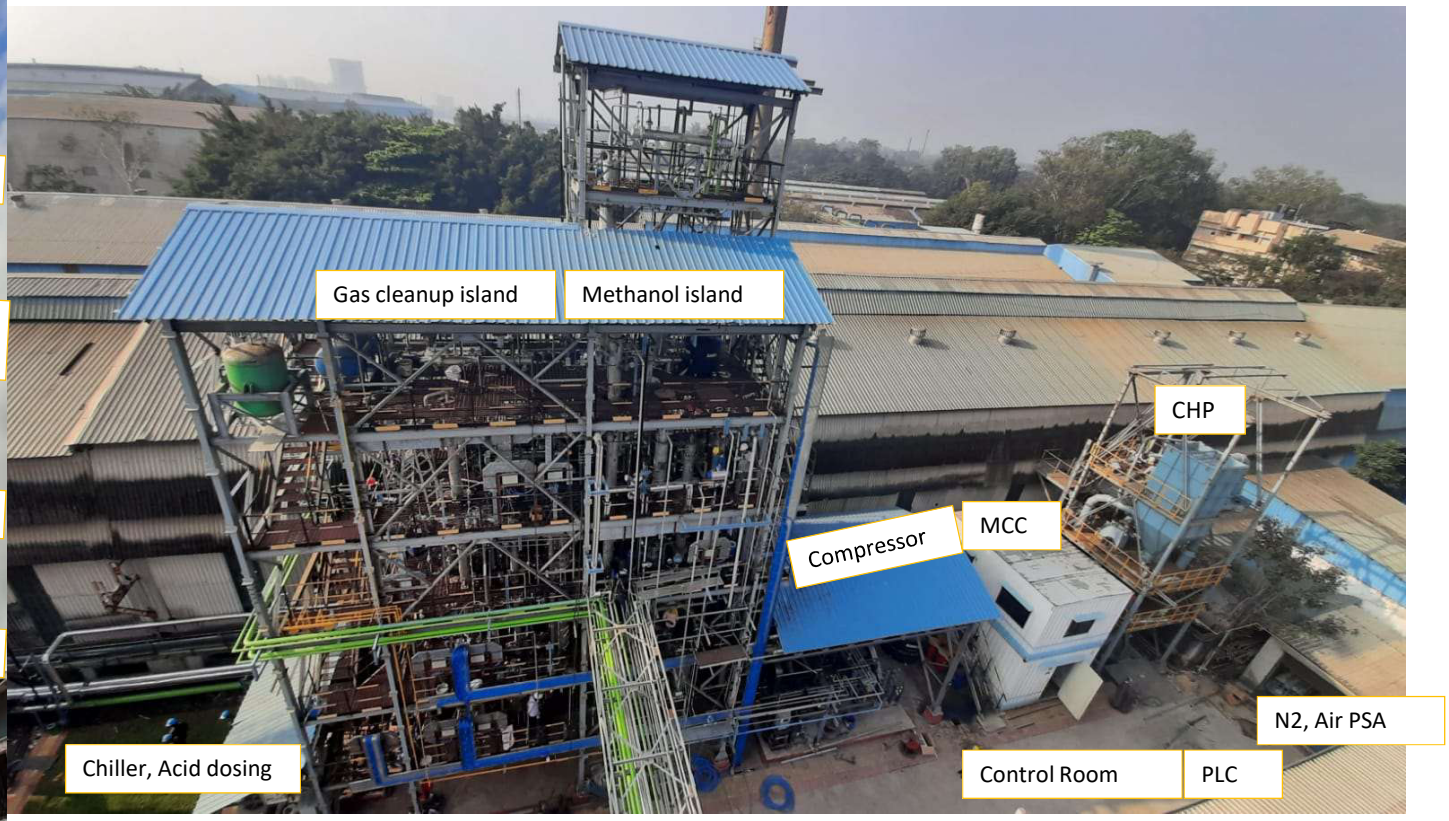
Gasifier island

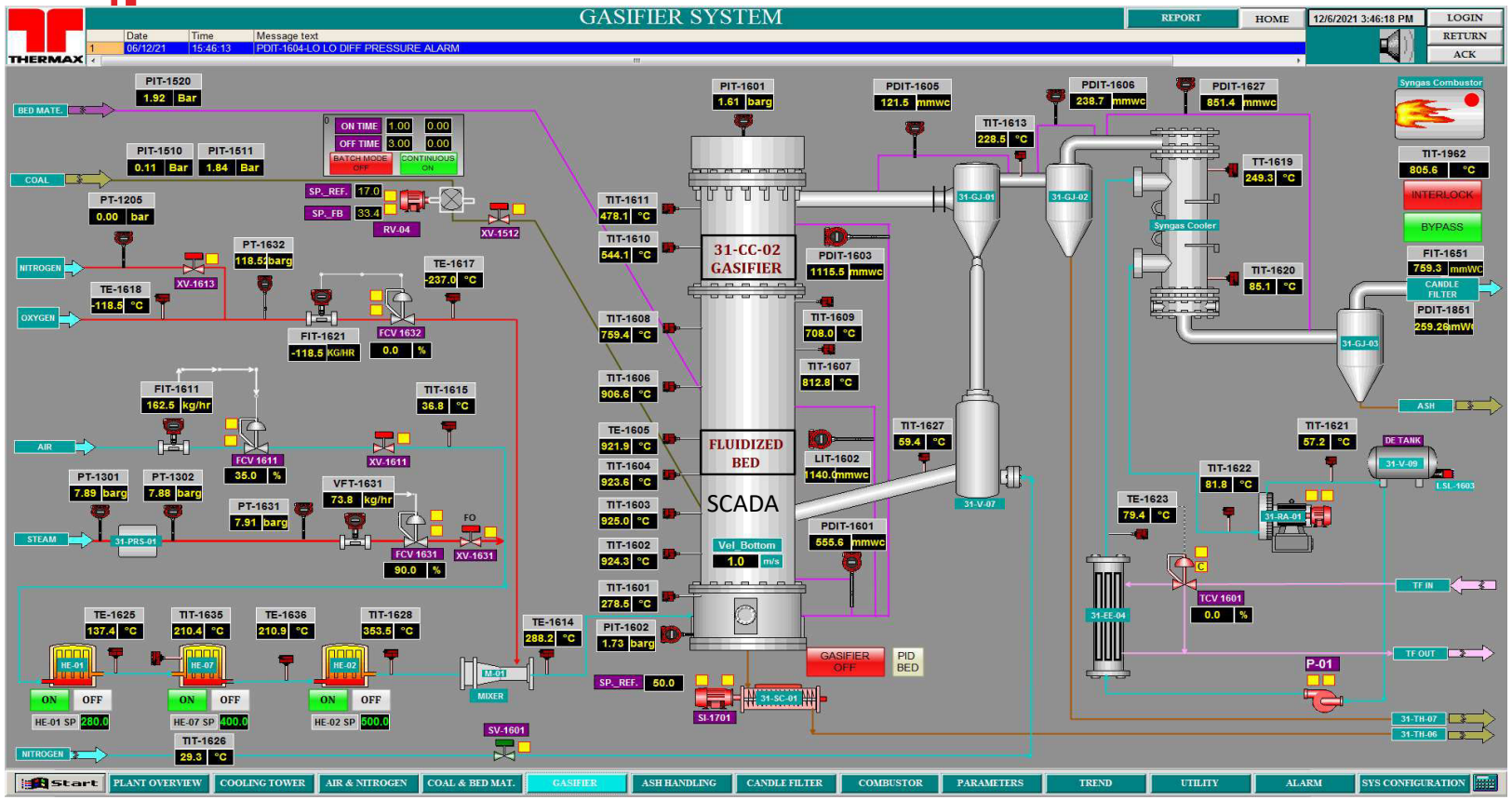


Front view Gas clean up and Methanol plant



First gasification trials completed…..Gas clean up island & Methanol island in pre-commissioning stage

Gasifier Performance

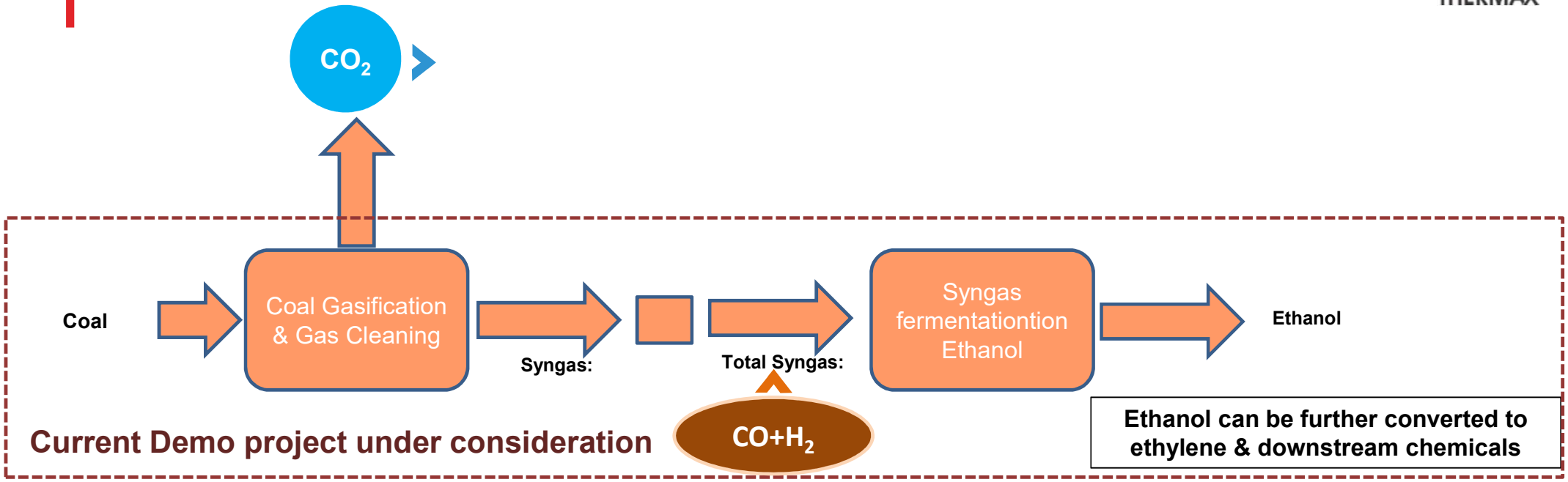


- Fully integrated plant , DCS SCADA controlled
- H2/CO ratio > 1.4
- Uniform bed temperature +/- 5 degree C
- Online analyser for continuous performance monitoring

	Raw Gas	N2 free	N2 and CO2 Free
CO	9.88	24.55	**38.94**
H2	14.07	34.96	**55.46**
CO2	14.88	36.97	
CH4	1.42	3.53	**5.60**
N2	59.75		

Typical Coal requirement = 4 kg per kg of methanol

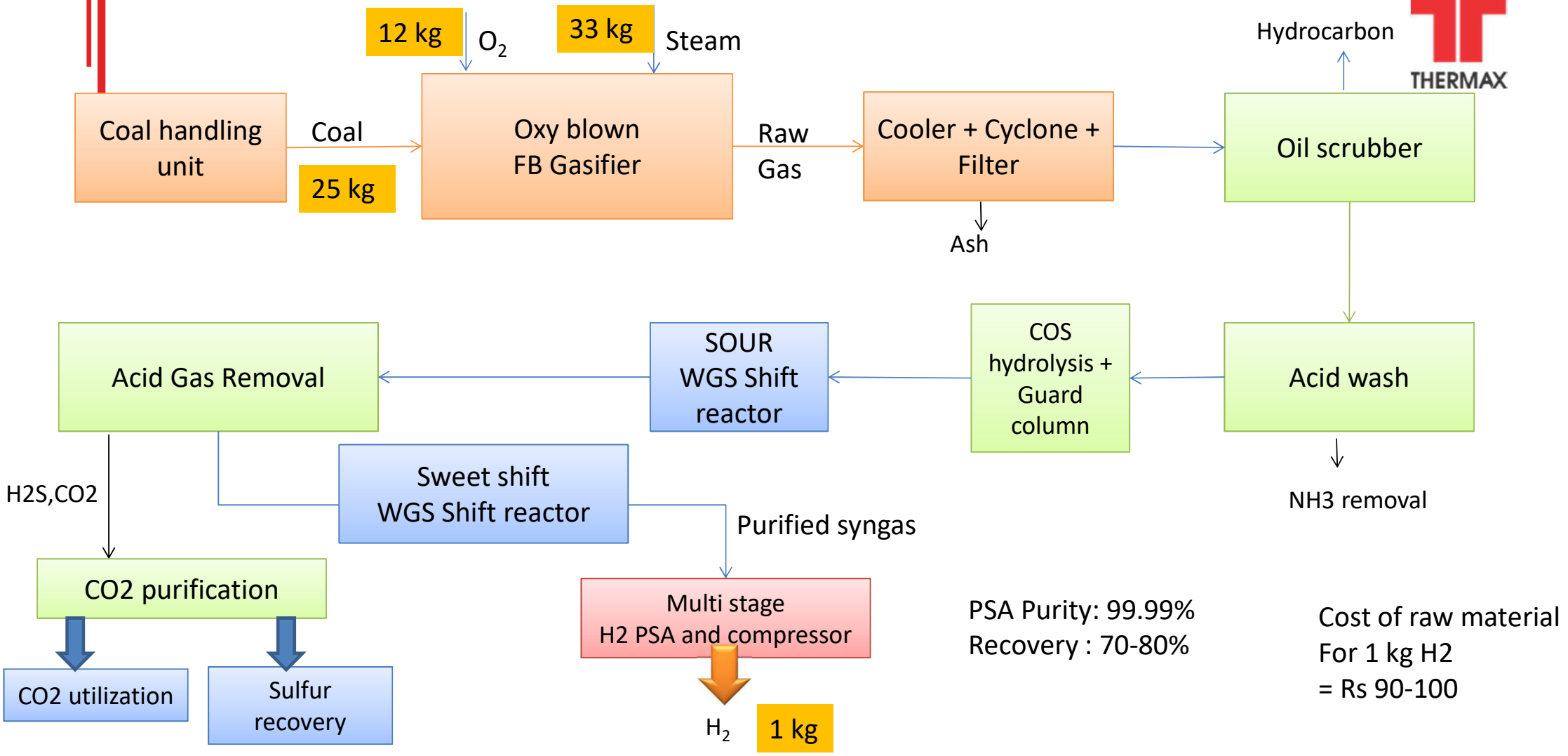
Coal Gasification for Ethanol Generation



Typical Coal requirement = 5 to 6 kg per kg of ethanol

Coal Gasification for H2 Generation

C TO H2: Typical Coal to Hydrogen detailed process steps

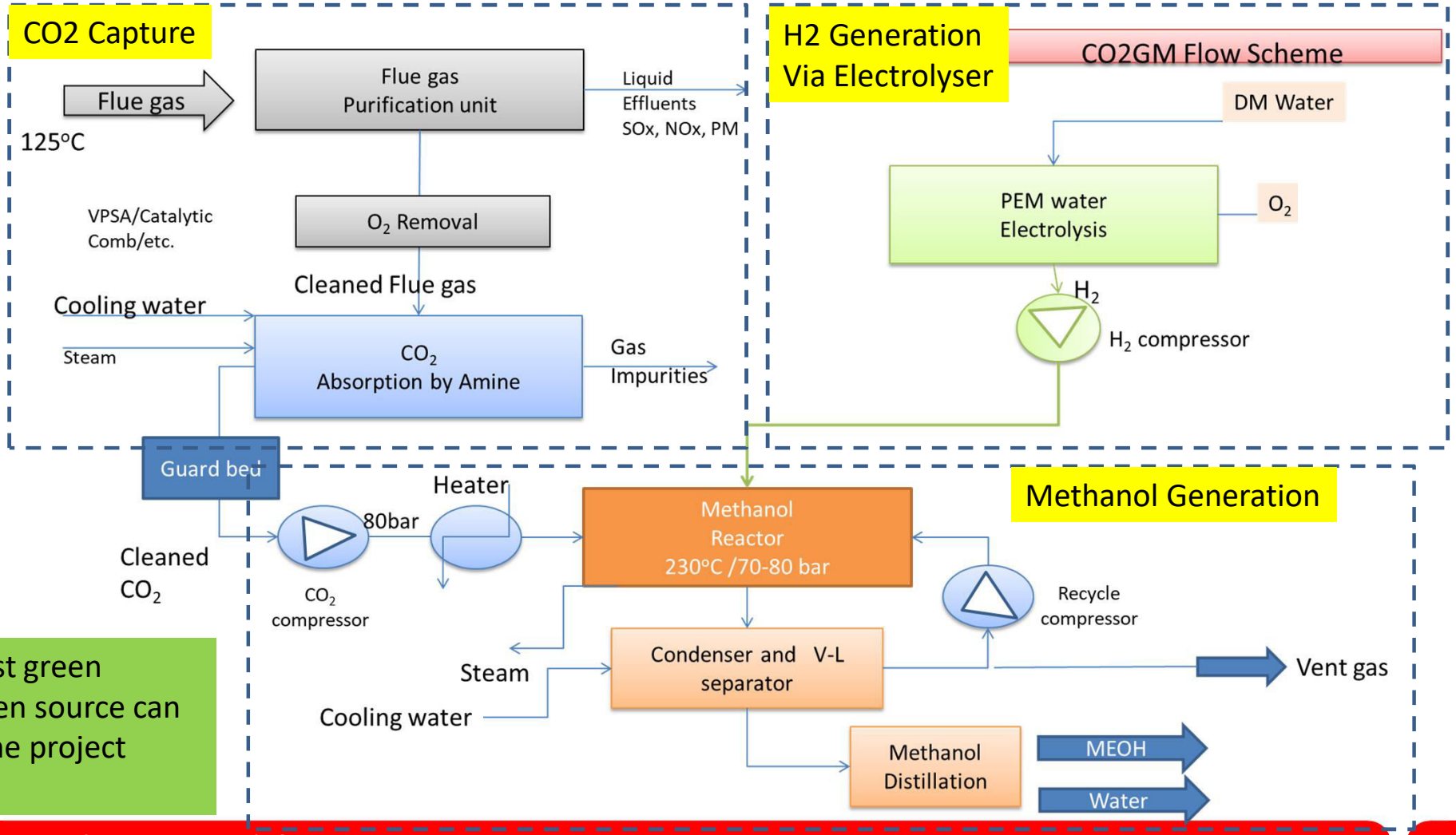


PSA Purity: 99.99%
Recovery : 70-80%

Cost of raw material
For 1 kg H2
= Rs 90-100

Towards Carbon Capture and Utilization (CCU)

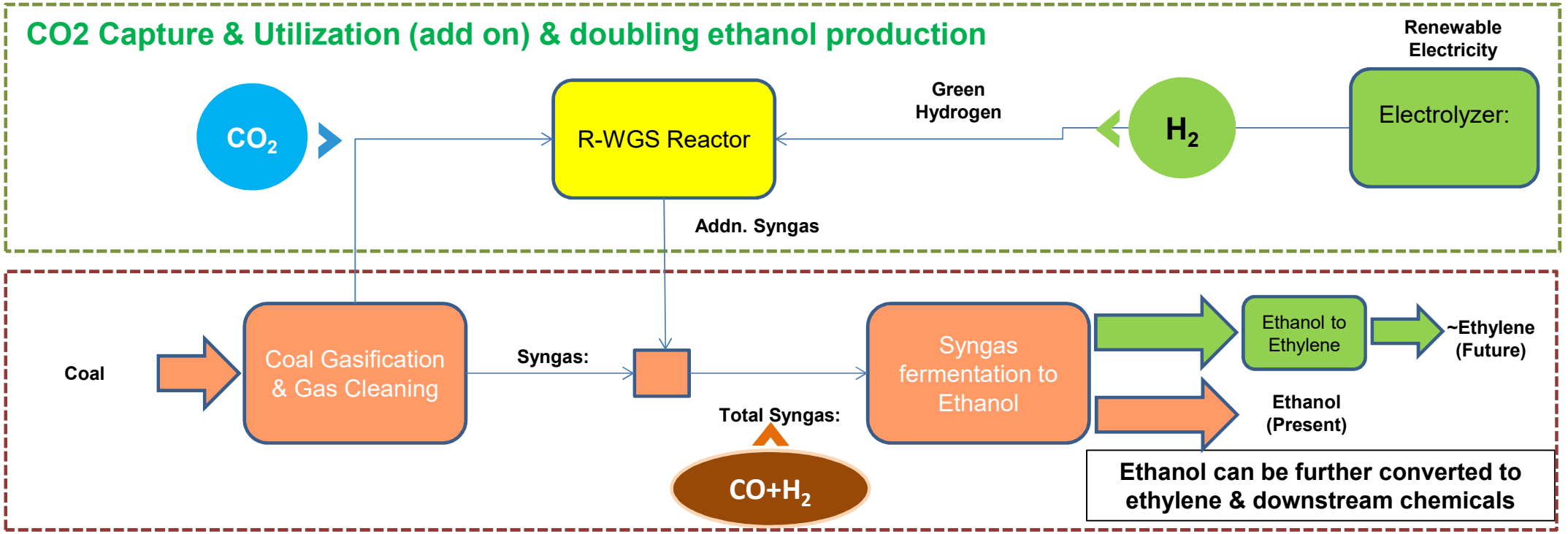
Proposed Project 01: Flue gas CO2 to Methanol – Feasibility studies



Low-cost green Hydrogen source can make the project viable

Proposed Project 02: Coal to Ethanol with CO2 utilization

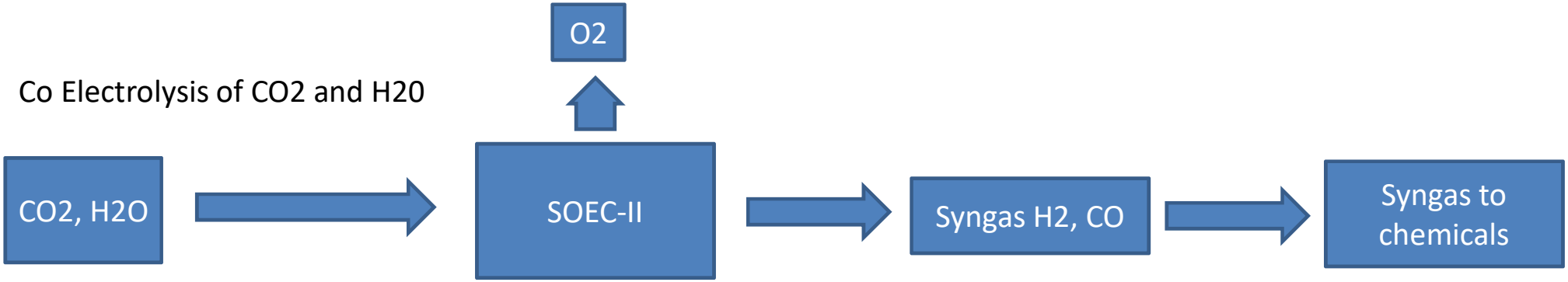
Test vehicle of the future to demonstrate and prove the potential of “green” hydrogen to make the “green” world a reality, thus providing impetus to India’s hydrogen mission….



CO2 utilization through solid oxide Electrolysis cell (SOEC)

THERMAX

Co Electrolysis of CO2 and H20



700 and 900 °C

Studies under initiation

TL is ready to provide end to end solution for emerging coal to Hydrogen program

- Decade worth of experience in Coal Gasification
  (5 demo projects)
- Expertise in Integration of various technology blocks beyond gasification
  (Energy integration, Gas cleanup, catalytic reactors, compression)
- Coupled with collaborative approach with key technology providers
  (National and international repute suppliers)
- Demonstrated capabilities in EPC and asset management
  (India and Abroad)

Thank you

A Complete Solution for Coal to Blue Hydrogen

Expert Committee – Roadmap for Coal based Hydrogen Production
Ministry of Coal

February 8, 2022

With You Today

Mr. Atanu Mukherjee
President & CEO

Mr. Abhijit Sarkar
Vice President

Dr. Suprotim Ganguly
Techno-Strategic Advisor

Mr. Phil Amick
Gasification Expert

Mr. Saurav Chatterjee
Business Leader

Mr. Arunava Maity
Process Design and Economics Leader

Mr. Arnab Adak
Practice Leader

Mr. Saptarshi Bhattacharya
Gas Processing Expert

Mr. Don Stevenson
Managing Director & Vice President, Energy Supply and Conversion

Mr. Vello Kuuskraa
President

Ms. Mei Chia
Senior Business Leader

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VP, Business Development & Licensing

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Convenor & In-Charge, National Centre of Excellence on Carbon Capture & Utilization

Dr. Arnab Dutta
Associate Professor, Chemical Engg

Ms. Kristjana M. Kristjánsdóttir
Director, Projects & Business Development

Key Discussion Points

01 Blue hydrogen is pivotal to a future hydrogen economy and green hydrogen at scale

02 Proven industrial-scale technologies exist for gasification of medium & **high** ash coals

03 Established technologies for producing **blue H_2** - gas cleaning & conditioning, CO_2 & H_2 separation, carbon capture, sequestration and utilization

04 Blue H_2 provides an economically viable pathway for industrial decarbonization

05 Demonstration scale **coal to blue H_2** plant - the first step towards a Blue H_2 economy

About Dastur

About Dastur

1. 65 years of experience in engineering, technology and consulting

2. Proven track record of Concept to Commissioning of over $100B of capital projects in energy, metals & mining across the world

3. Architecting marquee industrial-scale clean energy projects in India and abroad

4. Adapting and deploying best in class gasification and carbon capture technologies in India

5. Engineers, technologists and process modelers with 10,000+ years of cumulative experience

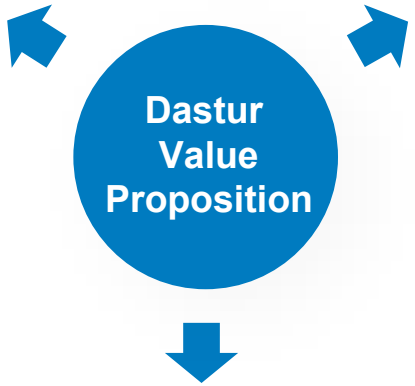
What We Do

Engineering

(System Design, Engineering & Integration, Project Management)

Technology

(R&D, Technology Licensing & Development, Process Simulation & Modelling)



Consulting & Cost

(Markets & Business Models, Project Conceptualization & Feasibility, Techno-Economics & Financial Analysis)

Clean Energy

- Coal Gasification
- H_2, Ammonia, Derivatives, Fuel blends
- H_2 Turbines, Clean Power Systems
- Methanol and derivatives

Carbon Engg.

- Carbon Capture and Design
- Carbon to Value (Methanol, Cured Concrete)
- CO_2 Transport – Clusters & Grids
- EOR & Sequestration

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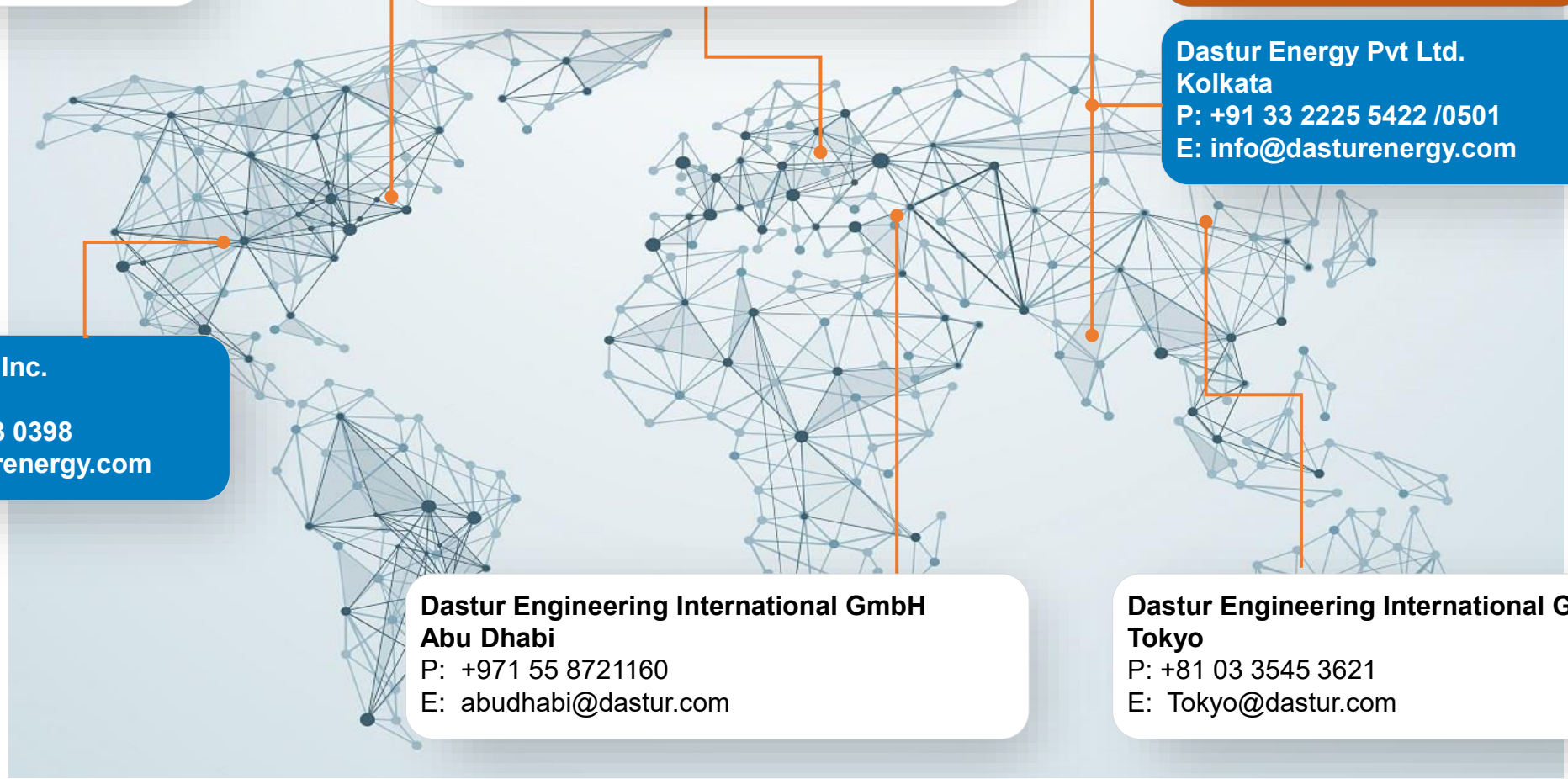

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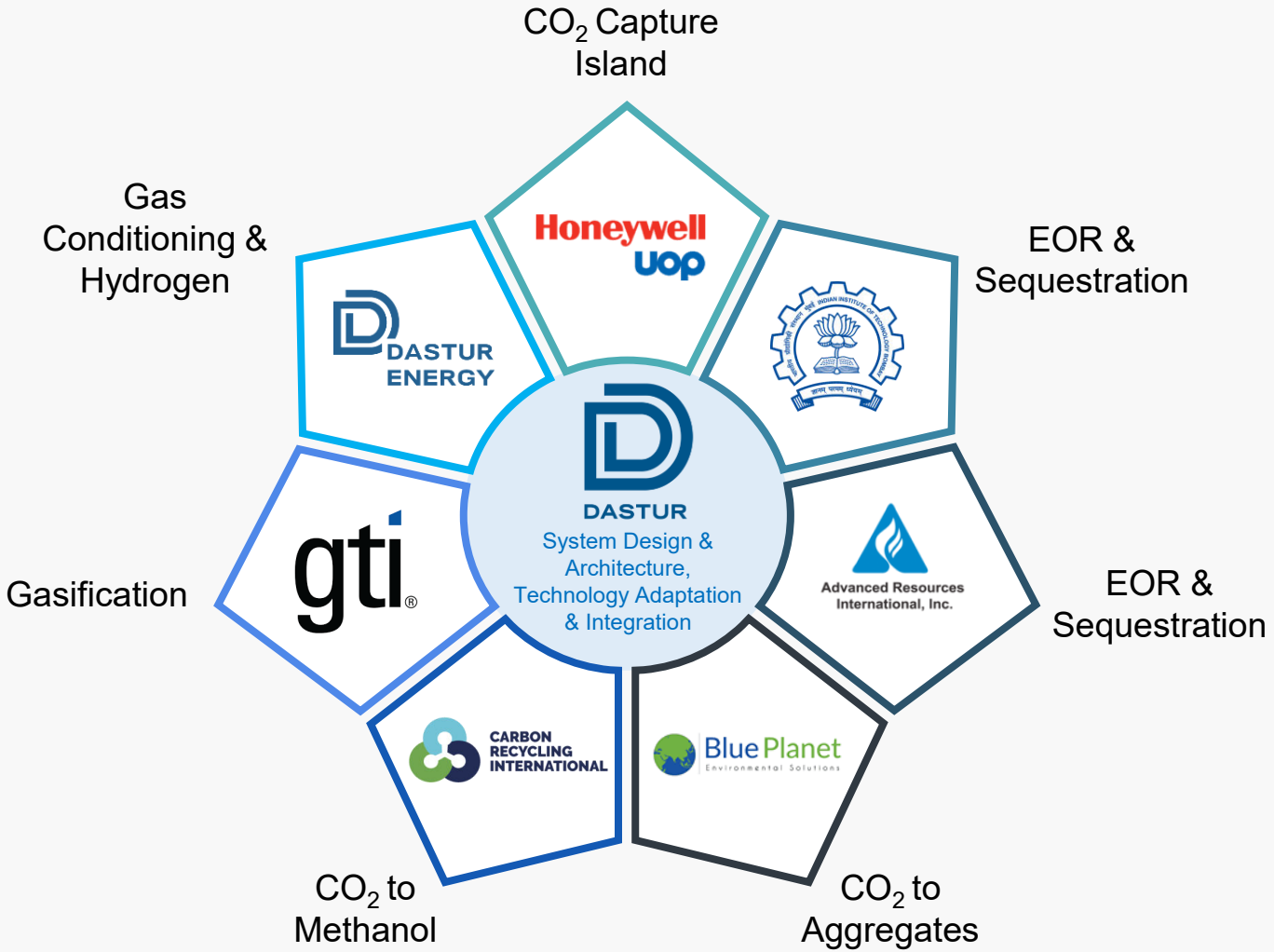
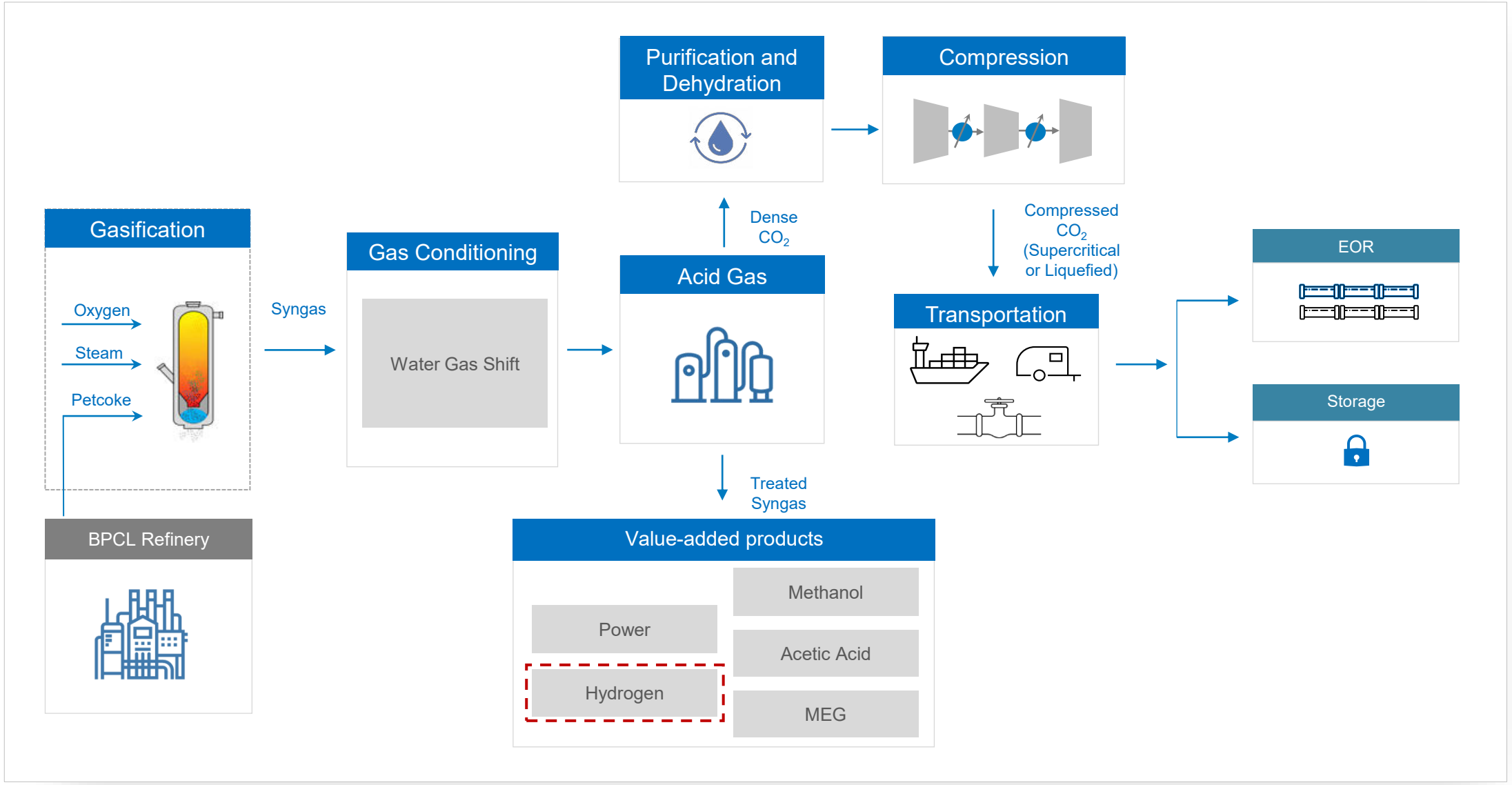
Our Partners for this Endeavour

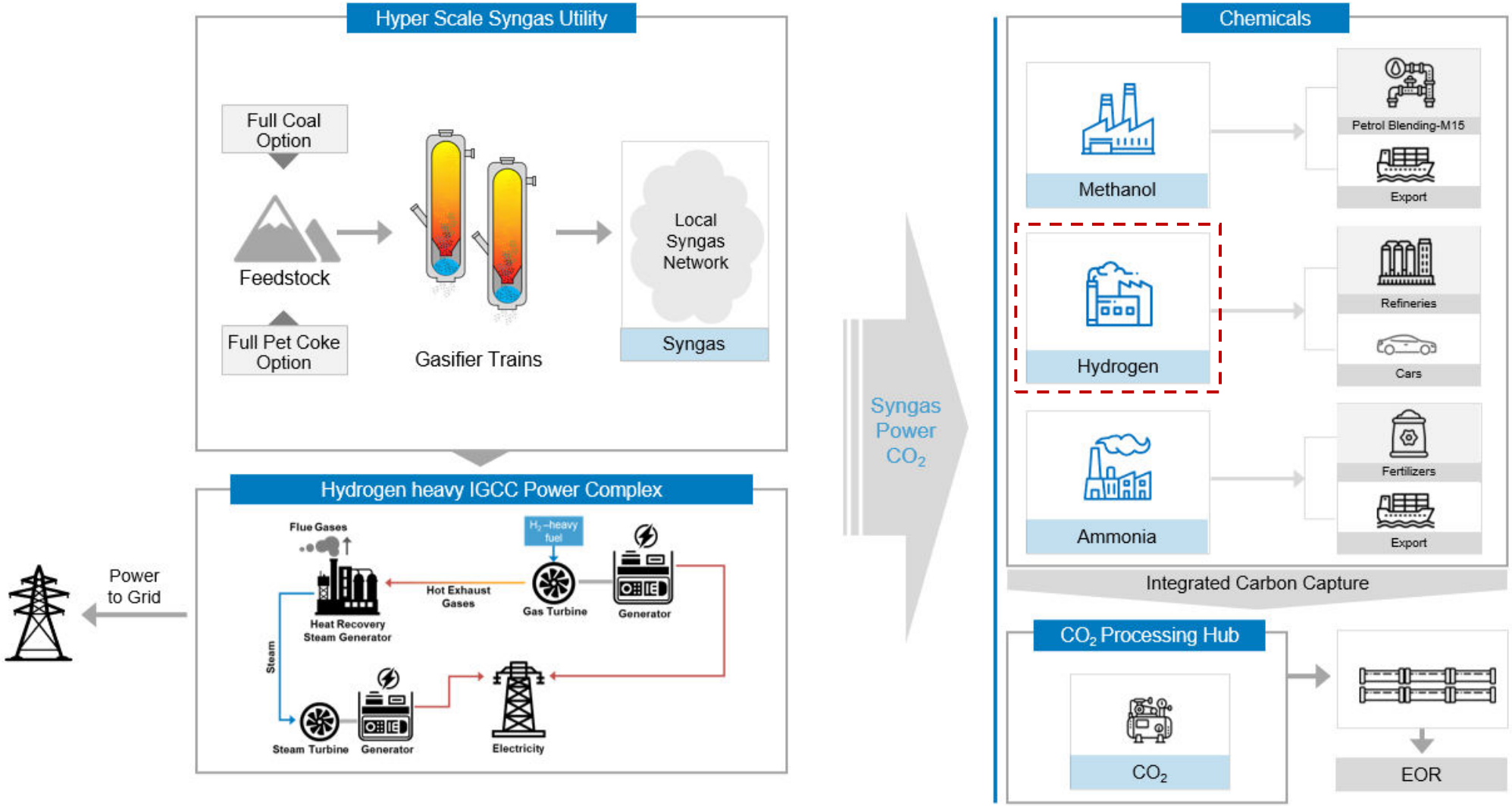


Few Relevant Case Studies

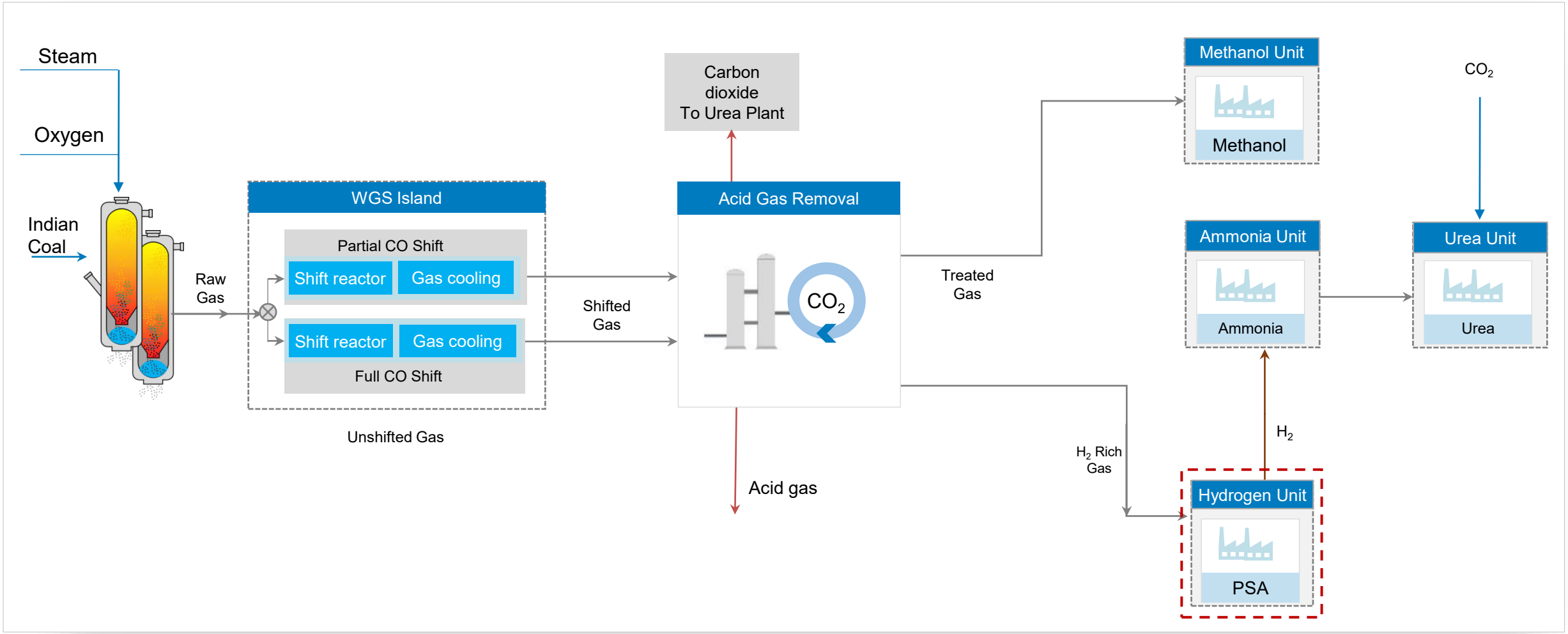
BPCL: 1.4 mtpa Petcoke Gasification to Produce 70 ktpa Clean Hydrogen and Other Clean Products with Carbon Capture



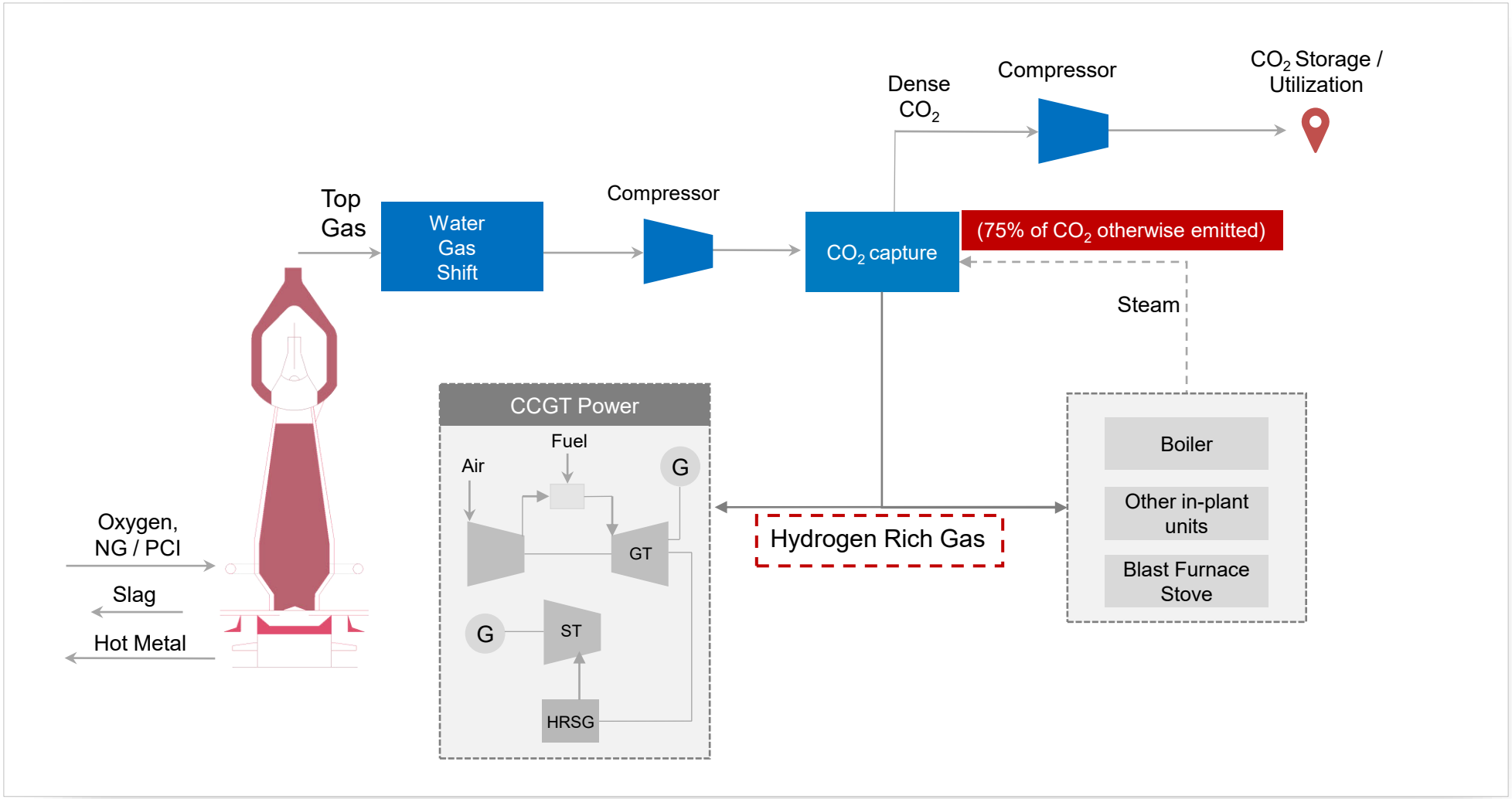
ADNOC: 4 mtpa Coal + 2.2 mtpa Petcoke Gasification Based Clean Power & Chemicals with 10 mtpa CO_2 for EOR



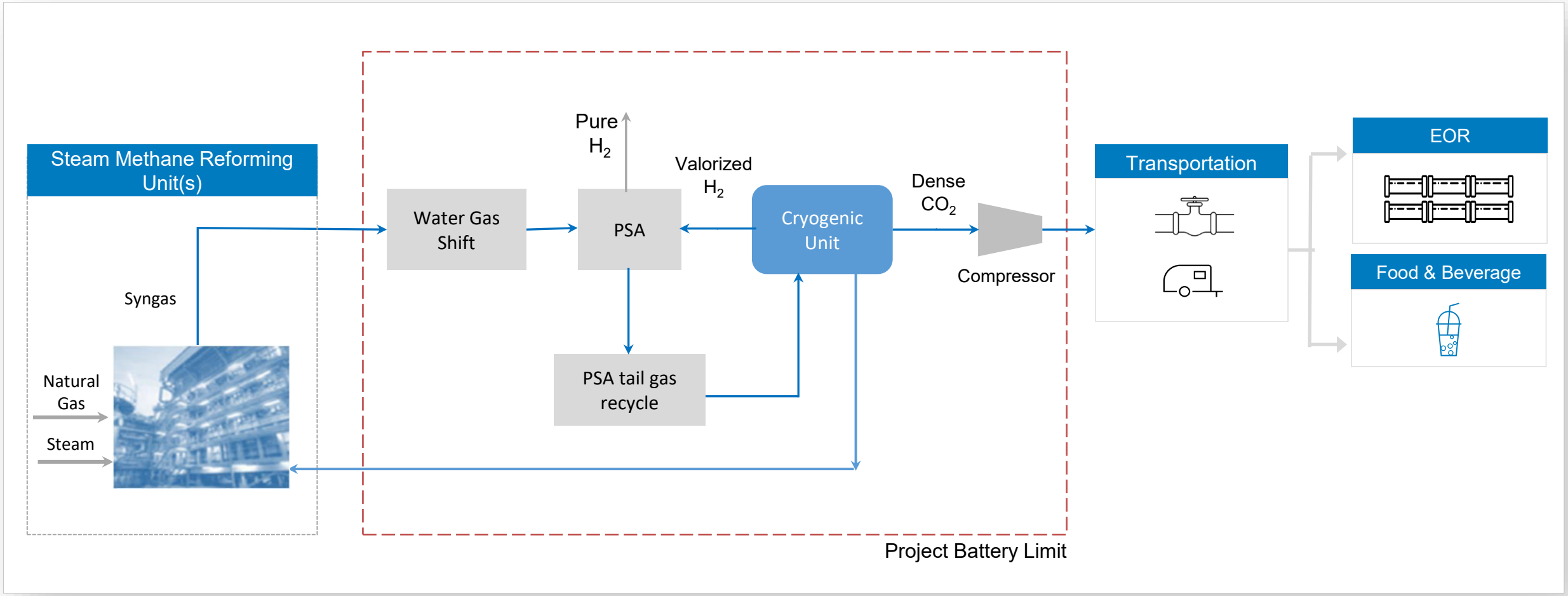
JSPL Angul: 3.5 mtpa Coal based 1 mtpa Methanol and 1.3 mtpa Urea Plant with 3.4 mtpa CO_2 Capture



Cliffs: First Industrial Scale Carbon Capture Demo Project in Steel in North America – for 2.8 mtpa CO_2 Capture for producing Low Emissions Steel



IOCL: First Industrial Scale Carbon Capture & CO_2 EOR Project in India – 0.7 mtpa CO_2 Capture and Utilization in EOR and F&B



Hydrogen Economy

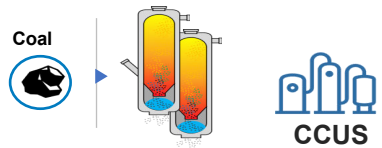
Seeding the Hydrogen Economy through Blue Hydrogen

Blue Hydrogen

Current Consumption of ~7 mtpa (oil refining, fertilizers)

Competitive cash cost of US$ 1-1.2 /kg

Drive the H_2 economy (NG spiking, steel etc.) beyond current uses

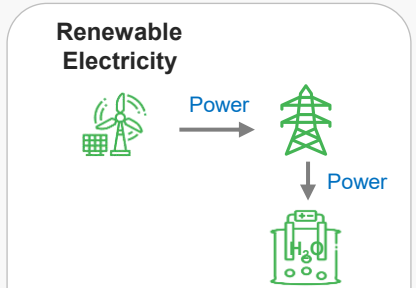


Green Hydrogen

2030 H_2 economy: 15 mtpa

Existing cost structure: US$ 5-6/kg

Blue H_2, renewables at scale & greening of grid will drive green H_2



H_2 H_2

H_2 injection in Nat Gas

Power

Steel

Oil & Gas

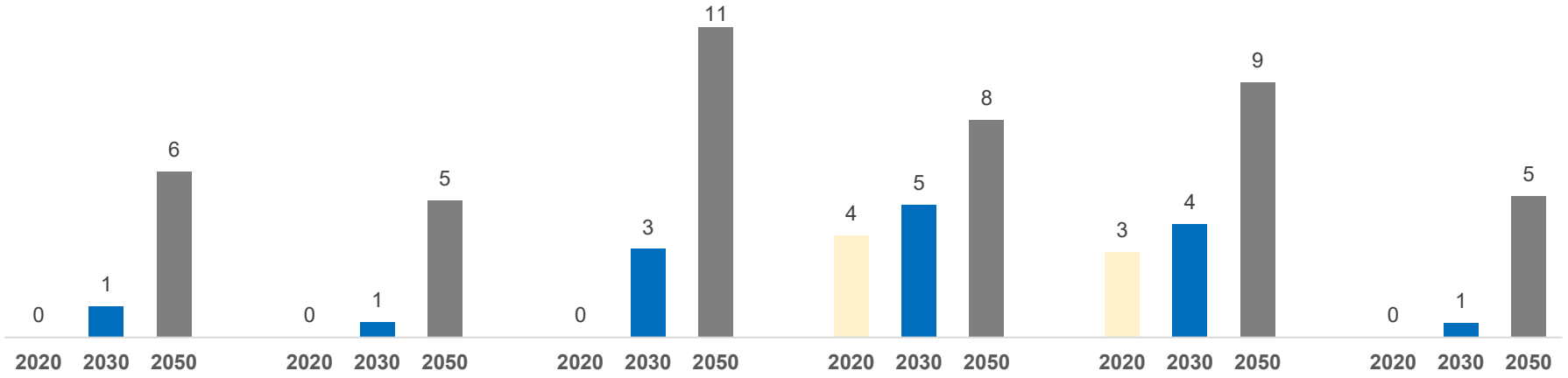
Fertilizer & Chemicals

H_2 Distribution

Heavy Transport

Energy Security, Economic Prosperity

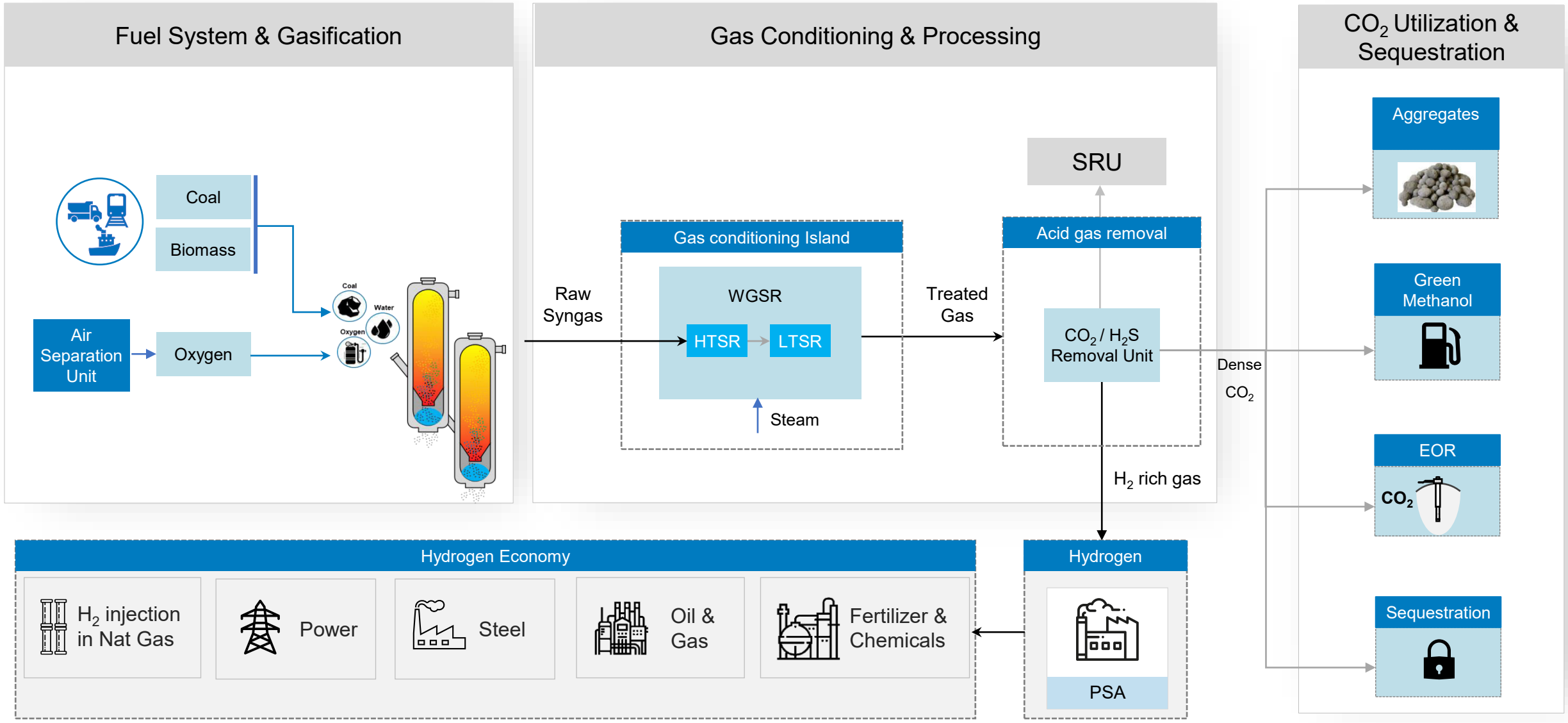
Hydrogen demand is expected to grow 2x from ~7mtpa (2020) to 15 mtpa (2030), and over 6x to 44 mtpa in 2050

Demand centres for low carbon hydrogen	H_2 injection in Nat Gas	Power	Steel	Oil & Gas	Fertilizer & Chemicals	Heavy transportation
Potential H_2 economy in India						
Key factors for driving demand	Policy push (National H_2 Energy Mission) for 20% blending	› Clean baseload support to renewables › Tech. development of H_2 turbines	› Low-emission steel making › Import of coking coal and price variability	› O&G sector growth and decarbonization › Sulfur emissions control	› Import substitution of fertilizers › Sectoral growth	› Decarbonization of heavy-duty transport › Distribution infrastructure

Steel, Fertilizer & Chemicals and O&G sectors are expected to drive H_2 demand

Producing Blue Hydrogen from Coal

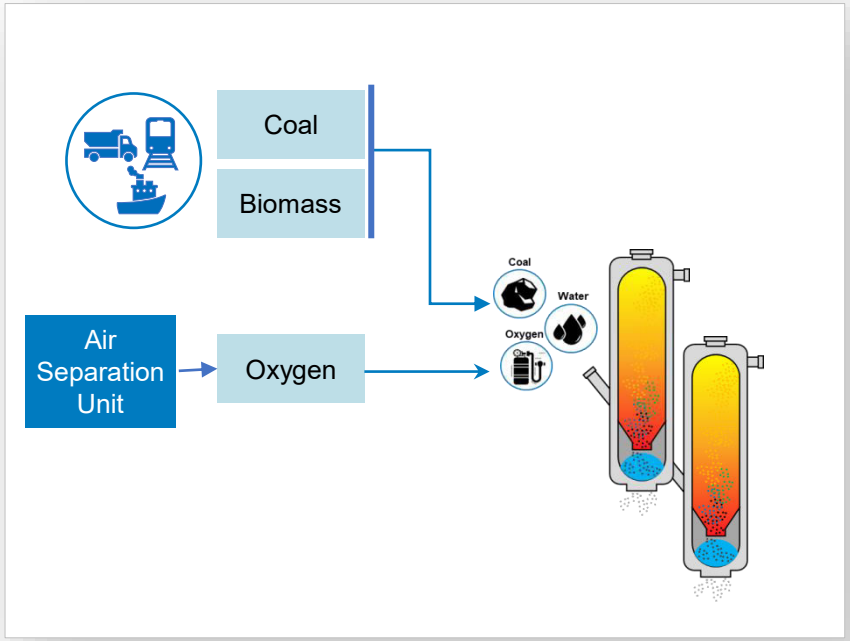
Flexible Gasification of Coal – Generation of Hydrogen with CCUS

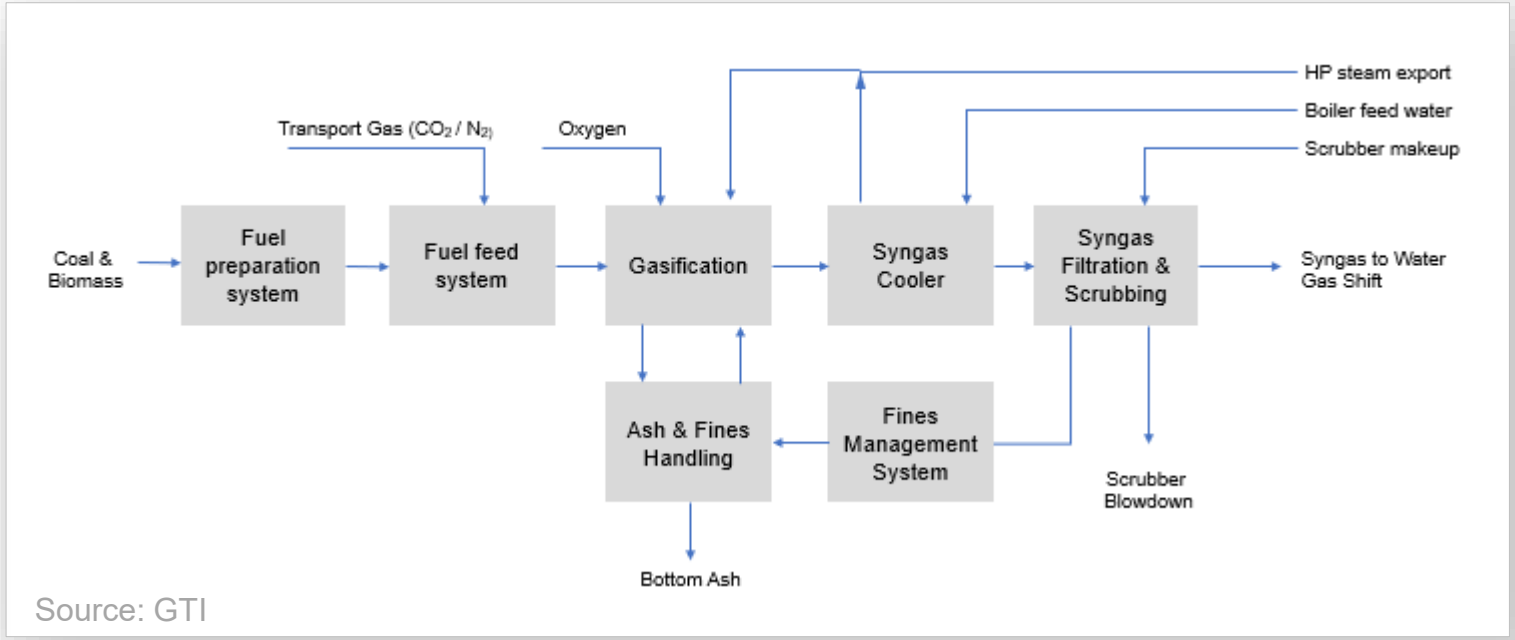


Key Technical Challenges and Approach towards **"Coal to Blue H_2"**

	Gasification of Indian coals	Gas cleaning and conditioning	Hydrogen separation	EOR & Geo-sequestration	CO_2 Utilization
Key challenges	› High ash coal - average > 35% › High SiO_2/Al_2O_3 and AFT above 1500 ^0C - needs high temp operation for fluid slagging for high ash coal usage	› Contaminants in raw syngas › Needs superheated steam	› Availability of high pressure gas › Selective separation of H_2 and other impurities from gas stream	› Onshore & offshore pore space mapping & characterization › No pilot/demo scale project in India › Risk management	› CO_2 to chemicals: low catalyst life (water poisoning), low yield & productivity, high PT › Process kinetics and techno-economics
Approach	**Fluidized Bed (FB) Gasification best suited** a. Can accept high ash and fine coals b. Non-slagging operation c. High reactivity of coal favours gasification	**Water Gas Shift and Carbon Capture** a. Acid Gas (SOx & CO_2) removal b. Better heat integration with gasification c. H_2S used to generate elemental sulphur or sulphuric acid	**Pressure Swing Adsorption Process** a. FB gasifier can operate at high pressure (>20 Bar.G) suitable for H_2 separation b. H_2 transportation easier at high pressure c. 99% pure H_2 can be generated	**Project Architecture and Conceptualization** a. MVA framework for risk management b. Proven tools & methodologies for pore space mapping & characterization c. Project conceptualization & site selection	**CO_2 to Methanol and Aggregates** a. Proven/high TRL technologies for CO_2 to aggregate and green methanol b. Cost competitive production of blue H_2 – reduces methanol cost

Fluidized Bed Gasification Technology – Best Fit for Indian Coals





Source: GTI

- Coal Preparation
- Dedicated Oxygen Plant
- Steam from Gasification Island

Non-Slagging

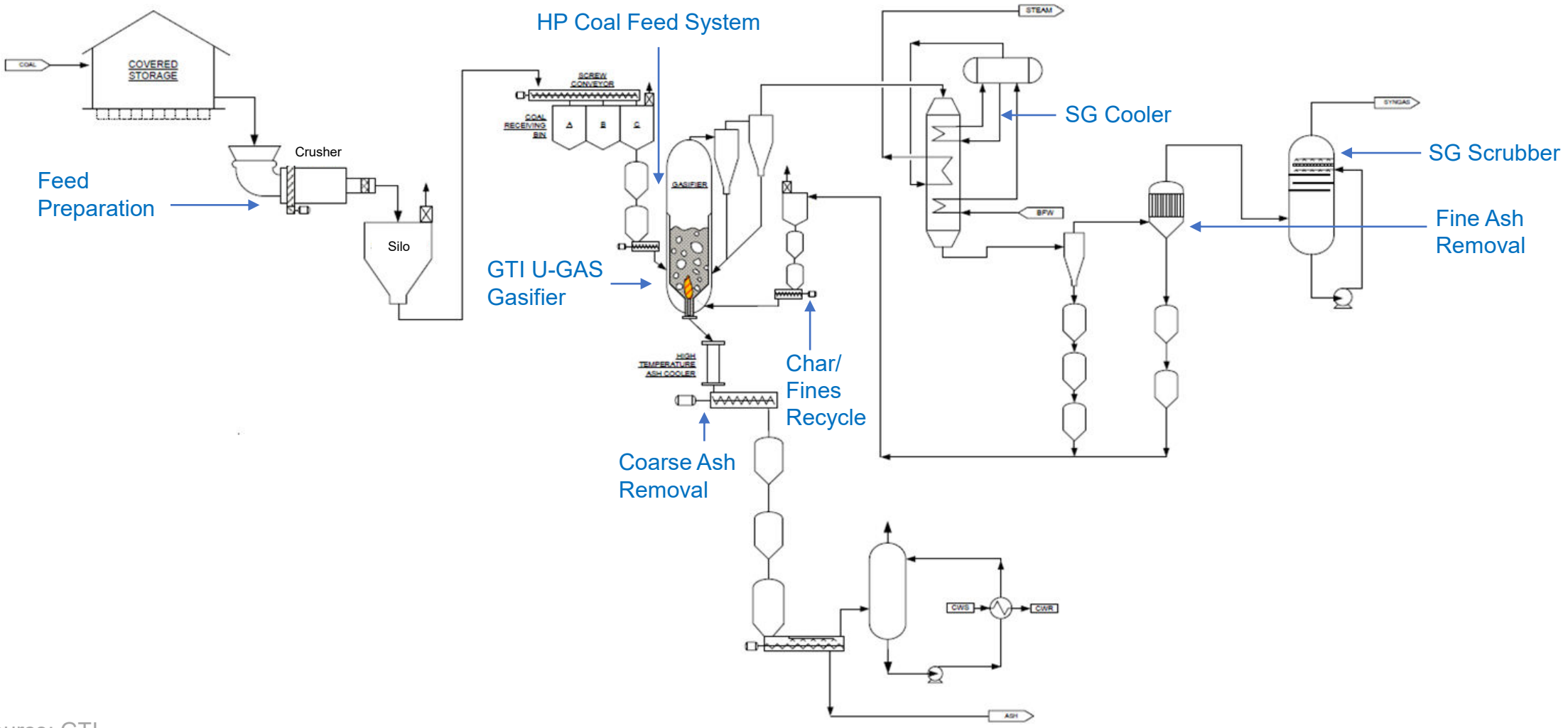
Suitable for Indian coal (G4 to G10) and high cold gas efficiency (~ 75-80%)

No by-product; moderate CAPEX/OPEX

Feed flexibility

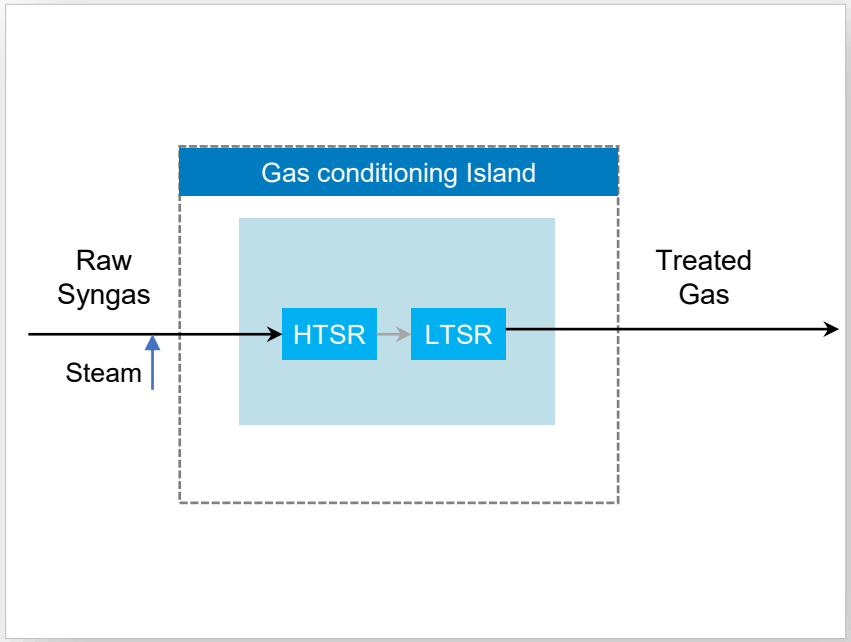
H_2/ CO ratio (~ 1.0).

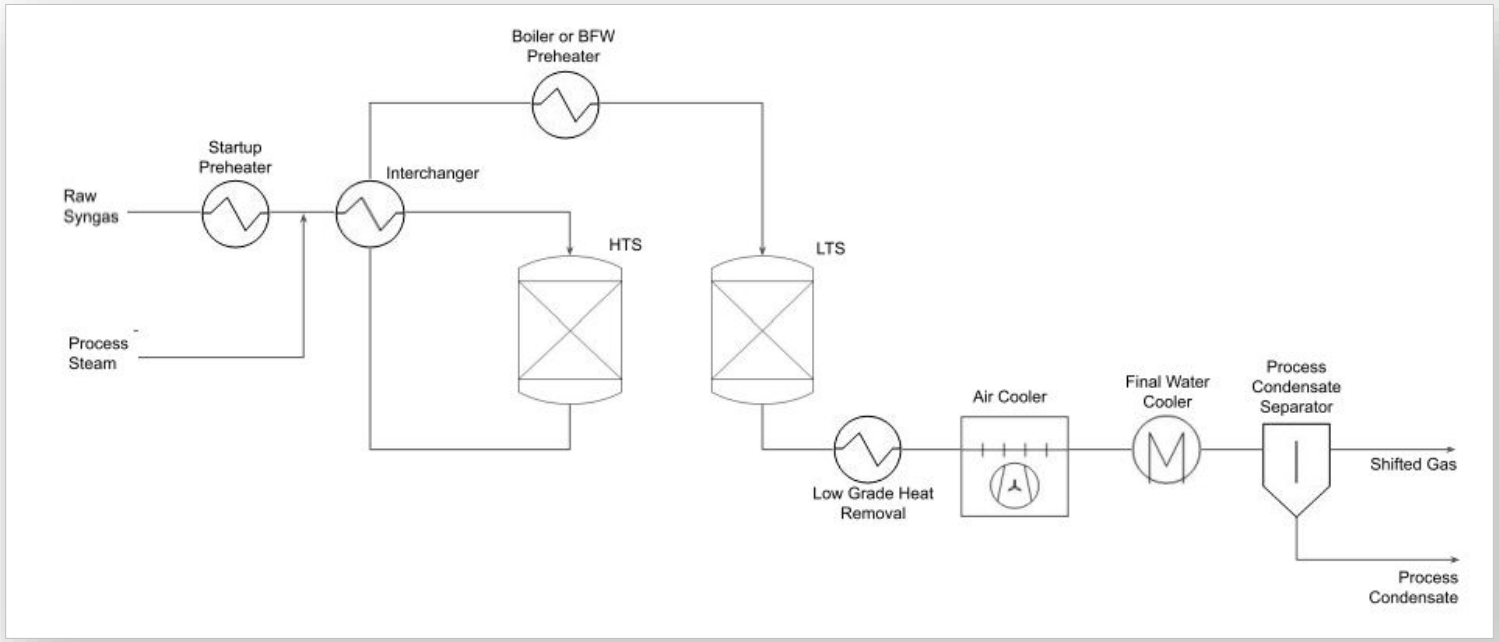
Gasification of Coal to Syngas



Source: GTI

Gas Cleaning and Conditioning





Source: DASTUR

- Raw gas preheating to 350-400 degrees C with Syngas as fuel
- Steam from Gasification Island; No external steam generator

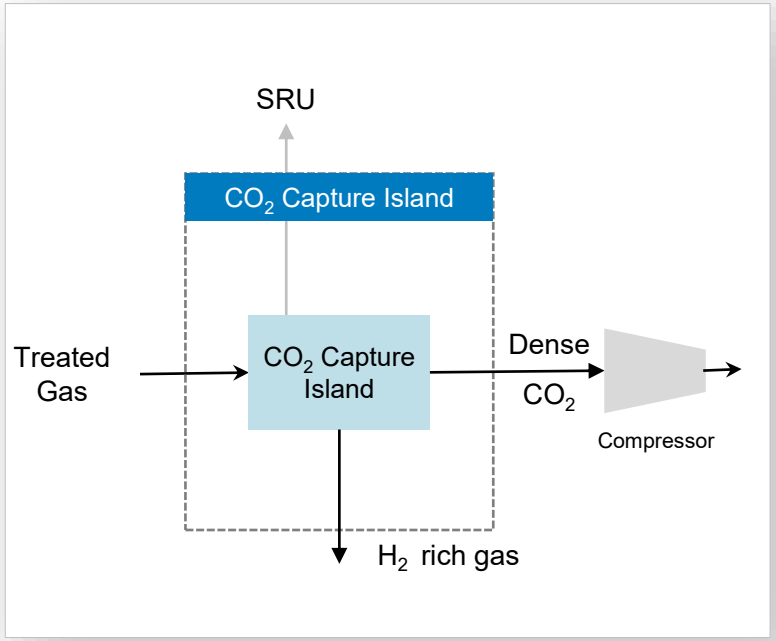
High temperature and low temperature shift for complete shift of CO to H_2

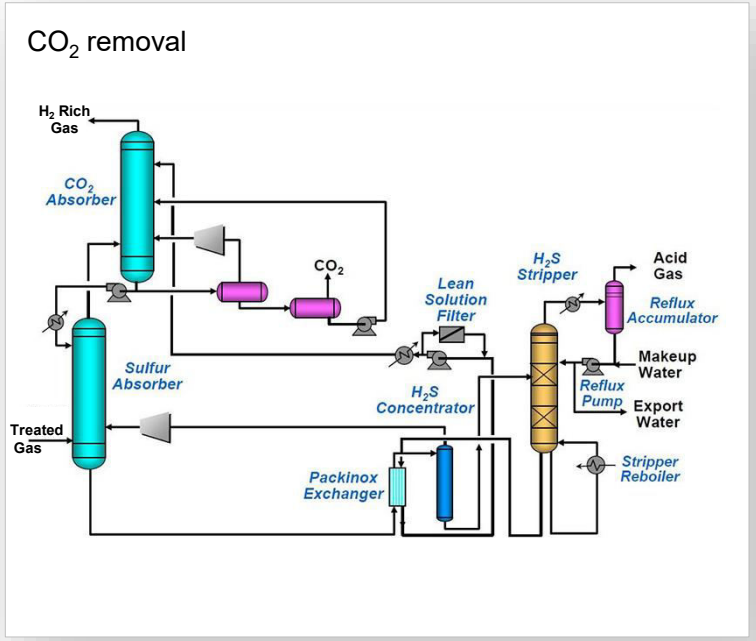
COS → H_2S conversion in high temperature shift; easy for removal

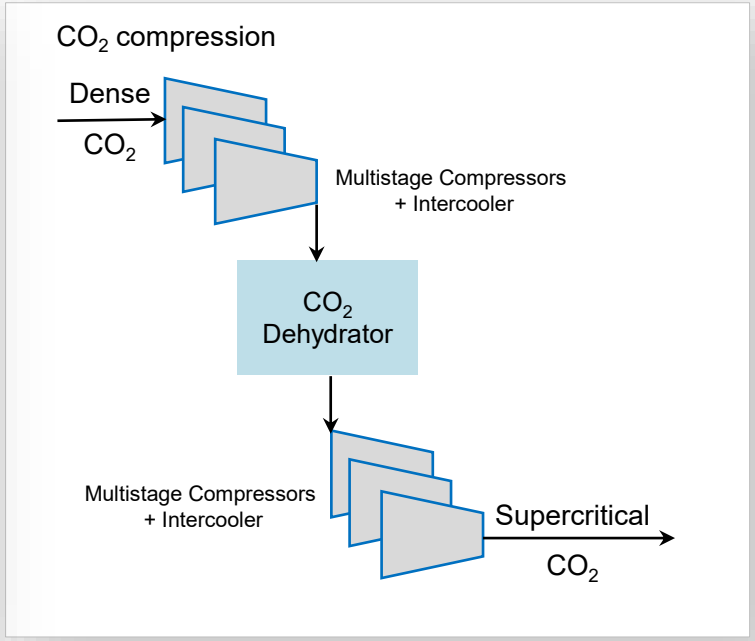
Low pressure steam generation

COS conversion

CO_2 Removal Unit







Source: UOP Honeywell

- Treated syngas input at high pressure

Physical absorption for high pressure operation

Selective removal of high concentration CO_2 and H_2S

Lower OPEX due to high CO_2 concentration and cheap solvent cost

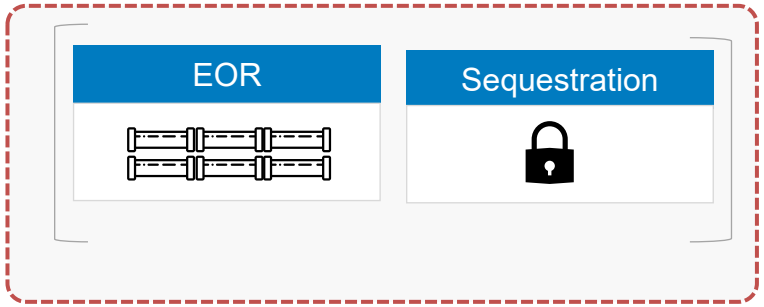
97% of CO_2 removal

CO_2 compression to super-critical stage for transportation

H_2S utilised for elemental sulphur or H_2SO4 production

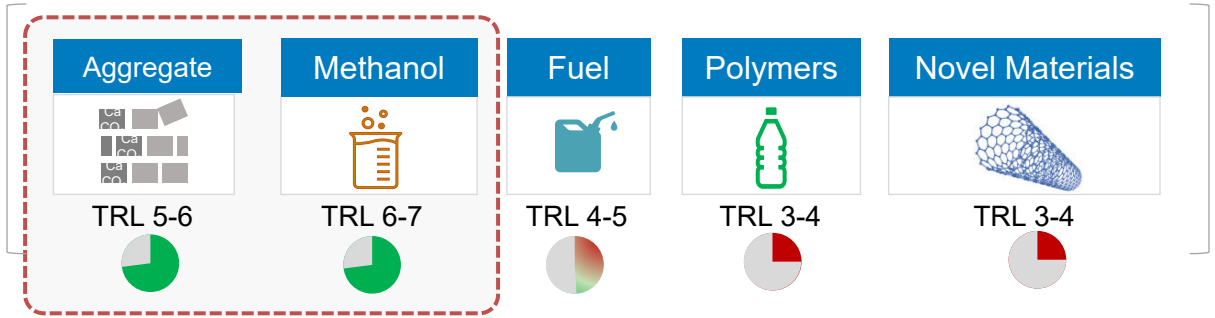
CO_2 Utilization: EOR, Sequestration, Aggregate and Methanol Production

Matured Commercial Technologies



- EOR potential in India: 2.8 Gt of CO_2
- Sequestration opportunity
  - Saline aquifers: 291 Gt
  - CBM: 2.8 – 5.3 Gt
  - Basaltic traps: 87 – 316 Gt

Promising Technologies Propositions



- Green methanol
  - Proven process which addresses issues with catalyst poisoning, yield, productivity & cost economics
  - Import substitution opportunity & fuel blending mandate
- Aggregates
  - Industrial scale deployments
  - Large market for aggregate and availability of industrial waste

Cost Economics of Blue Hydrogen

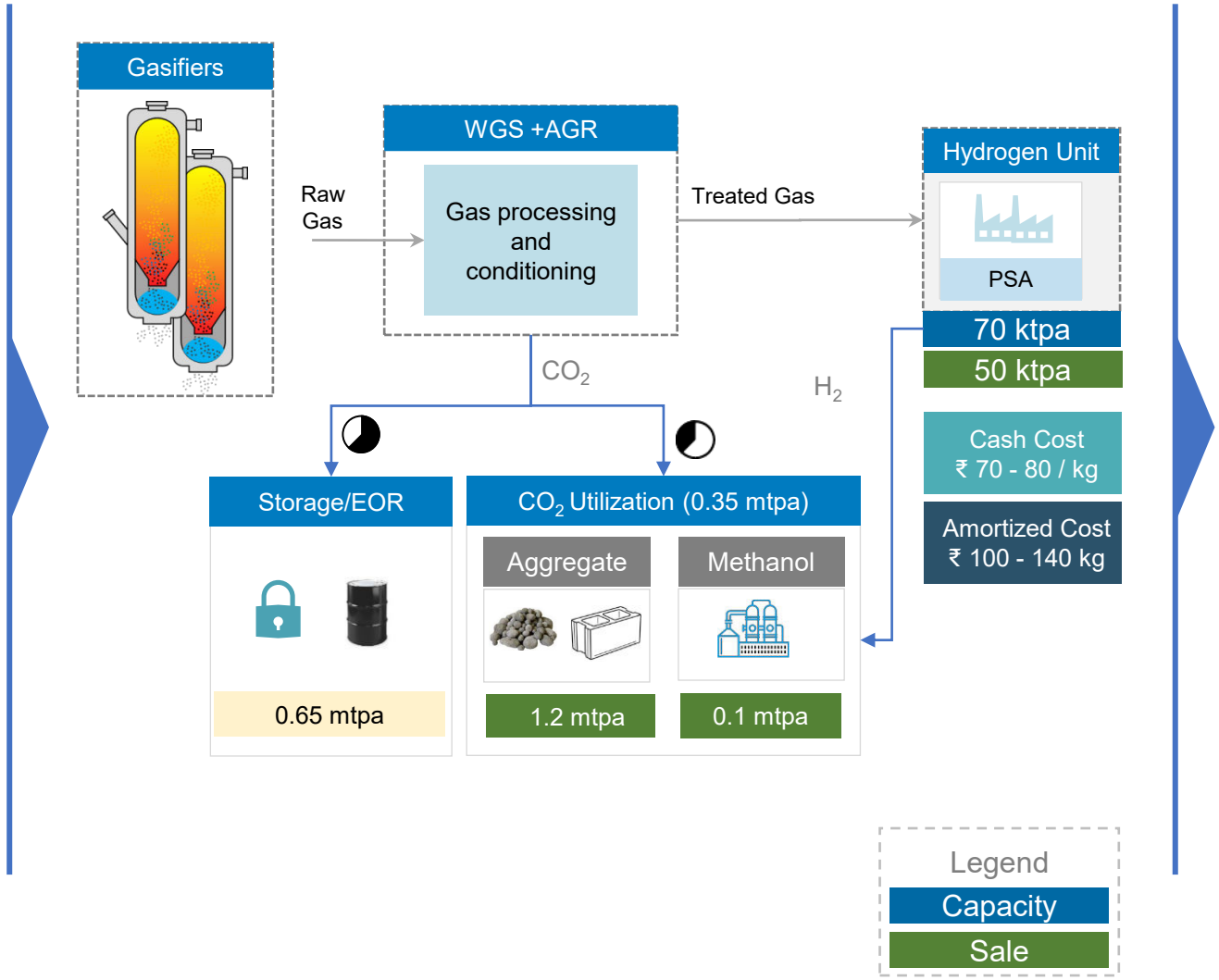
Schematic of a Hydrogen-based Gasification model with CO_2 Utilization & Sequestration

Coal
0.7-0.8 mtpa

Bio-mass
0.1-0.15 mtpa

Oxygen
2,000 tpd

Power
55 MW



Investment
₹ 3,500 Crore
Gasification + Gas processing + Methanol + CO_2 pipeline + auxiliaries (excluding CO_2 to mineral aggregates)

EBITDA
₹750 Crore
50 ktpa H_2 @ 2,500 $/Te + 0.1 Mt Methanol @500 $/Te + 1.2 Mt Aggregate @ 20% premium

Return on Investment
20% plus

Source: Dastur Analysis

Product wise Economics

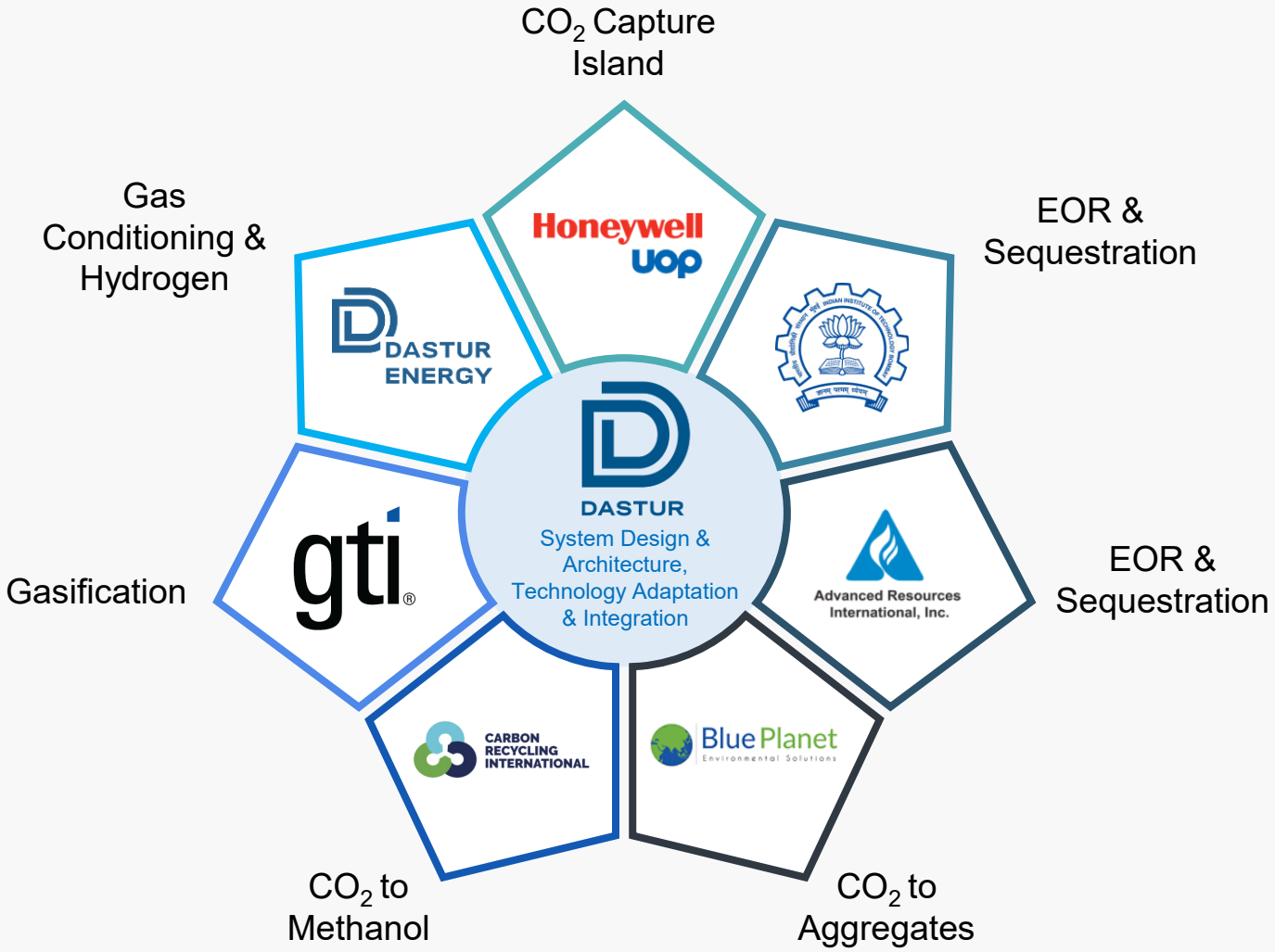
	Blue Hydrogen	Aggregate[1]	Green Methanol[2]	CO_2 Sequestration[3]
Products	**50 ktpa**	**1.2 – 1.5 mtpa**	**300 TPD**	**0.6-0.7 mtpa**
Investment	~ ₹ 3,000 Cr.	TBD	~ ₹ 300 Cr.	~ ₹ 200-400 Cr.
Revenue	~ ₹ 1000 Cr.	~ ₹ 100 Cr.	~ ₹ 400 Cr.	~ ₹ xx Cr.
Profit	~ ₹ 600 Cr.	~ ₹ 70 Cr.	~ ₹ 90 Cr.	~ ₹ xx Cr.
Return on Investment	~ 20%	-	~ 30%	~ XX%
CO_2 Abatement	0.7 – 1.2 mtpa (Compared to SMR based production)	0.2 – 0.25 mtpa	~ 0.15 mtpa	0.6 – 0.7 mtpa
				Need incentive/policy support

Note: 1. Additional revenue and profit over conventional concrete for premium (20%) as well as increase in quantity (0.4 mtpa) has been calculated for green aggregate
2. Green methanol selling price considered @ 500 US$/Tonne as prevailing in Europe
3. Cost of pipeline (~ 200 km and 12” dia.) is only considered. Exploration, modelling, survey, injection drilling, monitoring and inspection cost will be additional.

Source: Dastur Research

Our partners for Enabling Blue Hydrogen Economy in India

Our Partners for this Endeavour



Way Forward

Way Forward

Coal to hydrogen

- Blue hydrogen - a techno-economically feasible pathway for the hydrogen economy, industrial decarbonization and reaching India's net zero goals
- Industrial scale and commercially established technologies amenable for Indian coals and indigenization
- CO_2 to value-added products (concrete and chemicals) a powerful lever to drive decarbonization
- Critical to map and characterize the pore space in India for CO_2 sequestration
- Next steps – FEED followed by implementation & construction of a demonstration scale coal to H_2 plant

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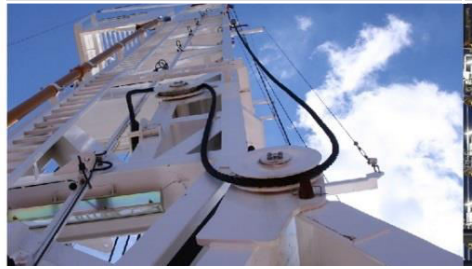
Gas Technology Institute (GTI)

FOR A BETTER ECONOMY AND A BETTER ENVIRONMENT

SUPPLY ▶ CONVERSION ▶ DELIVERY ▶ UTILIZATION




RESEARCH & DEVELOPMENT

PROGRAM MANAGEMENT

TECHNICAL/ ANALYTICAL

CONSULTING

TRAINING

COMMERCIALIZATION

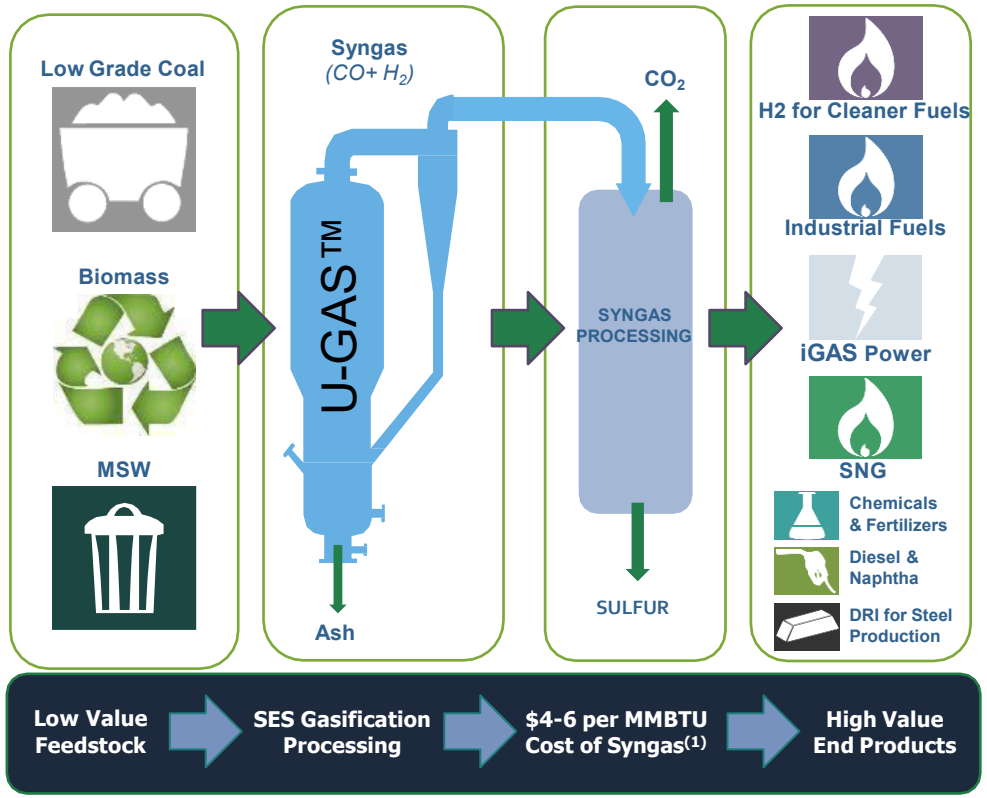
400+ EMPLOYEES

World-class piloting facilities headquartered in Chicago, USA

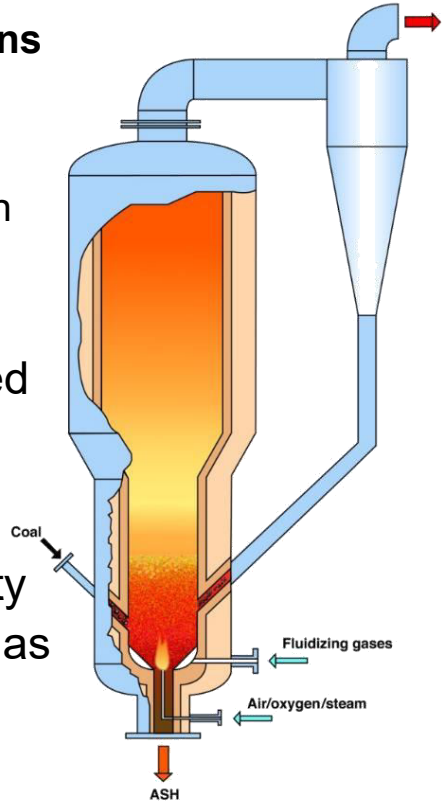
80 Year History of Turning Raw Technology into Practical Energy Solutions

GTI U-GAS™ Gasification Technology

- U-GAS is an advanced gasification system, differentiated by proven results and best-in-class performance.
- Over 40 years of development by GTI



- > Efficiency
  - carbon conversion 95-98%+ and cold gas efficiency 80%+
- > Flexibility
  - **coal, biomass and combinations**
  - high- to low-quality fuels
- > Versatility
  - Air-blown, enriched-air or oxygen
  - Atmospheric to high pressure
- > Operability
  - > simple, single-stage, deep bed thermal flywheel
  - > low temperature with long component life
  - > Up to 50% turndown capability
  - > Potential for tar / oil free syngas
- > Commercially deployed
  - Commercially deployed
  - 12 gasifiers in 5 plants



GTI U-GAS™ Gasification Feedstock Flexibility Demonstrated

- Feedstocks tested with U-GAS™

Bituminous and Sub-bituminous Coals

- Western Kentucky No. 9, washed & ROM
- Western Kentucky No. 9 and 11, Camp
- Illinois No. 6, Peabody No. 10 and Crown III
- Pittsburgh No. 8, Champion and Ireland
- Australian, Bayswater No. 2, Sydney Basin
- Polish, Silesia
- French, Merlebach - ROM
- Utah - ROM
- Colombian
- Chinese, Shen Fu, ZaoZhuang, Shen Mu
- Indian, North Karanpura, washed and ROM
- Ambre Subbituminous coal

Low Rank Coals

- Montana Rosebud, Colstrip Wyoming, Big Horn, North Dakota lignite, Freedom
- Saskatchewan Lignite
- Inner Mongolia lignite

Coke Char, Peat, Wastes

- Metallurgical Coke, U.S., China, Poland
- Western Kentucky No. 9 coal char
- Illinois No. 6 coal char
- Finnish Peat, Viidansuo and Savaloneva
- Automobile Shredder Residue
- Oil shale

Biomass

- Finnish waste wood and pulp mill waste
- Danish Willow
- Danish Straw
- Pelletized alfalfa stems
- Pelletized waste wood
- Bagasse
- Rice straw
- Chicken litter
- Sorted MSW

	Tested Result Range by Site		
Coal Characteristic	ZZ	Yima	U-GAS Total (including Pilot Plants)
Ash Content (wt %)	10 - 55	19 - 52	1 - 55
Moisture Content (wt %)	4 - 43	1 - 10	1 - 43
Volatile Matter (wt %)	12 - 40	20 - 30	3 - 69
Fixed Carbon (wt %)	24 - 66	22 - 38	6 - 83
Sulfur (wt %)	0.6 - 4.0	0.2 - 2.0	0.2 - 4.6
Ash Softening Temperature (°C)	1,112 - 1,450	1,277 - 1,488	1,040 - 1,460+
Heating Value (kcal/kg)	3,100 - 6,100	2,625 - 5,076	3,050 - 7,700

GTI U-GAS™ Gasification Reference Projects

- 12 Commercial Gasifier Systems
- Outstanding Performance
- Strong Design Basis for India

30 Years R&D (GTI)

ZZ Syngas Project

Yima Large Scale Chemical Project

CHALCO 7 SGT Gasifier Systems – Industrial Fuel Gas

2 Trains
22,000 nm3/hr syngas
400 MTPD coal per gasifier
3 Bar Operating Pressure

3 Trains
300,000 mt/yr methanol
1200 MTPD coal per gasifier
10 Bar Operating Pressure

2 Trains
80,000 nm3/hr syngas
432-576 MTPD coal per gasifier
3 Bar Operating Pressure

1 Train
28,000 nm3/hr syngas
365 MTPD coal per gasifier
3 Bar Operating Pressure

4 Trains
120,000 nm3/hr syngas
315-432 MTPD coal per gasifier
4 Bar Operating Pressure

U-GAS™ Gasification Projects

Project Owner and Location	Plant Type	Gasification Pressure	Feedstock	Feed Rate	Final Product	Commission Date
GTI, Chicago, IL	Process Development Unit (PDU)	3.5 Mpa (508 psi)	Coal, Lignite	5 t/d	Syngas	1977
GTI, Chicago, IL	Process Development Unit (PDU)	3.4 Mpa (490 psi)	Biomass	12 t/d	Syngas	1987
Tampella, Tampere, Finland	Pilot	2.5 Mpa (363 psi)	Coal/Biomass	80 t/d	IGCC	1992
Westinghouse Electric, Maui, Hawaii	Demonstration	2.1 Mpa (305 psi)	Biomass	100 t/d	Syngas	1997
GTI, Chicago, IL	Pilot	2.8 Mpa (406 psi)	Coal, Biomass	40 t/d	Syngas	2004
Andritz-Carbona, Skive, Denmark	Commercial	0.28 Mpa (40 psi)	Biomass	165 t/d	CHP	2008
SES, Zeozhuang, China	Commercial	0.22 Mpa (30 psi)	Anthracite, Bituminous, Lignite Coal	400 t/d	Methanol	2008-01
SES, Yima, China	Commercial	1.0 Mpa (145 psi)	Local Long Flame Coal, Shenmu Coal	1440 t/d	Methanol	2012-10
SES, China Aluminum Group – Shandong China	Commercial	0.33 Mpa (48 psi)	Inner Mongolia Coal	480 t/d	Fuel Gas	2015-05
SES, China Aluminum Group – Shanxi China	Commercial	0.23 Mpa (33 psi)	Weakly Caking Coal	360 t/d	Fuel Gas	2015-12
SES, China Aluminum Group – Henan China	Commercial	0.25 Mpa (36 psi)	Shenmu Coal	300 t/d	Fuel Gas	2017-03

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HONEYWELL INC. - Overview

NYSE: **HON** | ~**970** sites | ~**110,000** employees | Charlotte, NC| **Fortune 100**

Aerospace

Our products are used on virtually every commercial and defense aircraft platform worldwide and include aircraft propulsion, cockpit systems, satellite communications, and auxiliary power systems.

Building Technologies

Our products, software, and technologies are in more than 10 million buildings worldwide, helping customers ensure their facilities are safe, energy efficient, sustainable, and productive.

Performance Materials and Technologies

We develop advanced materials, process technologies, automation solutions, and industrial software that are revolutionizing industries around the world.

Safety and Productivity Solutions

We improve enterprise performance and worker safety and productivity with automated material handling and voice scanning and mobile computing technology, software, solutions, and personal protective equipment and sensing technology.

Honeywell Connected Enterprise

Honeywell Connected Enterprise (HCE) was established in 2018 to accelerate software development and IIoT solutions. We focus on software development, from the gateway to end-user applications, bringing scale and capability across all of Honeywell. These new offerings are then commercialized through Honeywell's businesses.

Aligned to Key Global Macro Trends

Sustainable Technology Solutions Wins

Plastics Recycling

- Honeywell's **UpCycle Process Technology expands the types of plastics that can be recycled** and can produce feedstock used to make recycled plastics with a lower carbon footprint
- Announced intent to form a **joint venture with Avangard Innovative, America's largest plastics recycler,** to build an advanced recycling plant in Texas that utilizes UpCycle Process Technology

Next-Generation Batteries

- Honeywell provides **smart energy storage solutions** to address the needs of a wide range of commercial and industrial customers
- Partnered with FREYR Battery to help enable customers to transition to clean power generation, **producing batteries that can be used at large solar and wind renewable power generation sites**

Low-Cost Carbon Capture

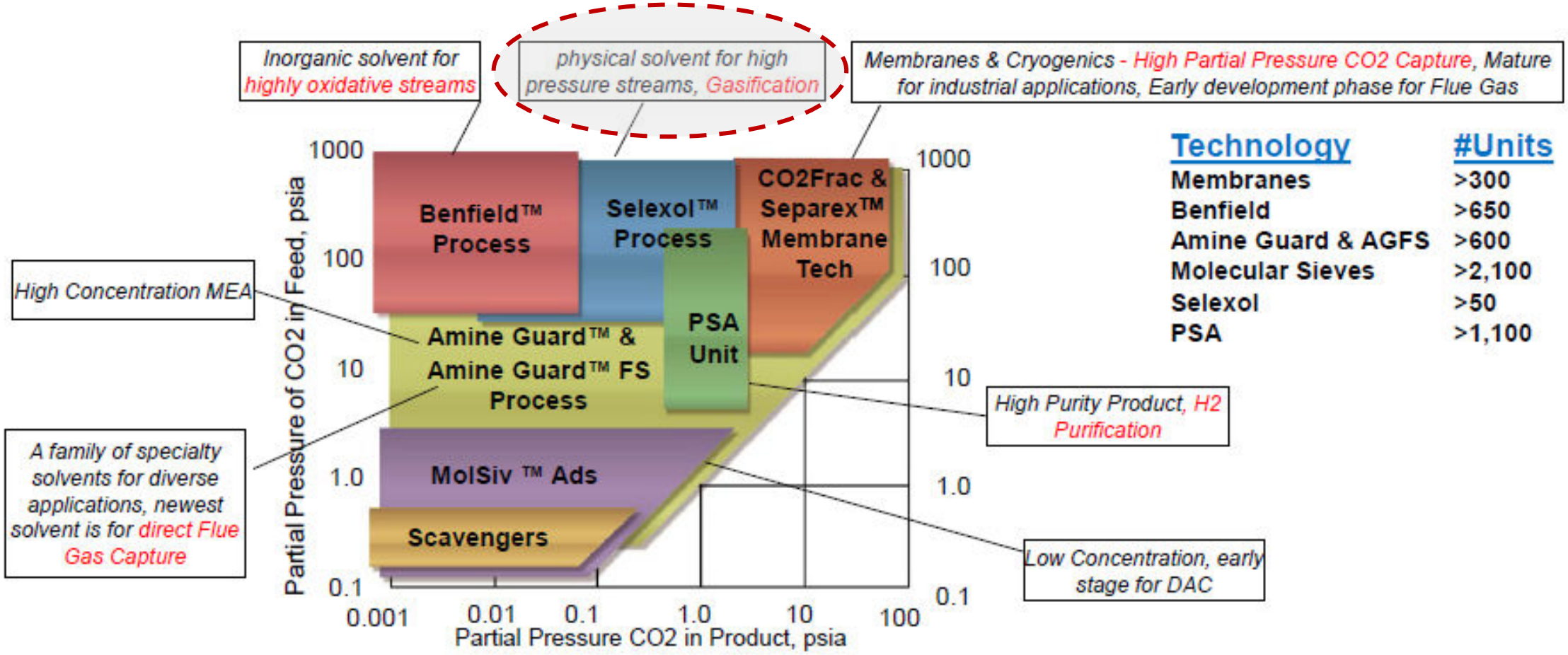
- Honeywell UOP provides process and separation technologies with the capacity to **capture and sequester CO_2**
- Agreed to leverage UT Austin's proprietary advanced solvent technology to **create a new offering for power, steel, cement, and other industrial plants to lower emissions from combustion flue gases**

Green Fuels

- Honeywell UOP's innovative renewable technologies produce **high quality, drop-in fuels from sustainable sources**
- **6 recent wins in UOP's Ecofining™** renewable fuels technology, including a large multinational oil company
- Using Ecofining™, Diamond Green Diesel's expansion, DGD2, with a capacity of 430M gallons of Renewable Diesel per year, started up ahead of schedule and on budget; DGD3 due 2H23, brings total capacity to 1.2B gallons per year

Continued Innovation to Drive the Energy Transition

UOP'S Extensive CO_2 Capture Portfolio



Technology	#Units
Membranes	>300
Benfield	>650
Amine Guard & AGFS	>600
Molecular Sieves	>2,100
Selexol	>50
PSA	>1,100

UOP's Technology Portfolio Makes a Natural Partner for CO2 Capture

Honeywell CO_2 Capture References

Fertilizer Plant
~1 Mt captured annually
Tech: SeparALL

2xTrains @
5 Mt/Train
Capturing 8.4 Mt annually
Tech: Cryo Fractionation + SeparAll

FPSO
0.5 Mt capacity
Tech: Separex Membrane

Energy Co.
1.5 Mt capacity
Tech: SeparALL

FPSO
26 Mt capacity
7 Mt captured in '20
Tech: Separex Membrane

2.3 Mt capacity
Will capture 1.7 Mt annually
Tech: Benfield

Installed & Capturing with CCUS

Installed & CCUS Ready

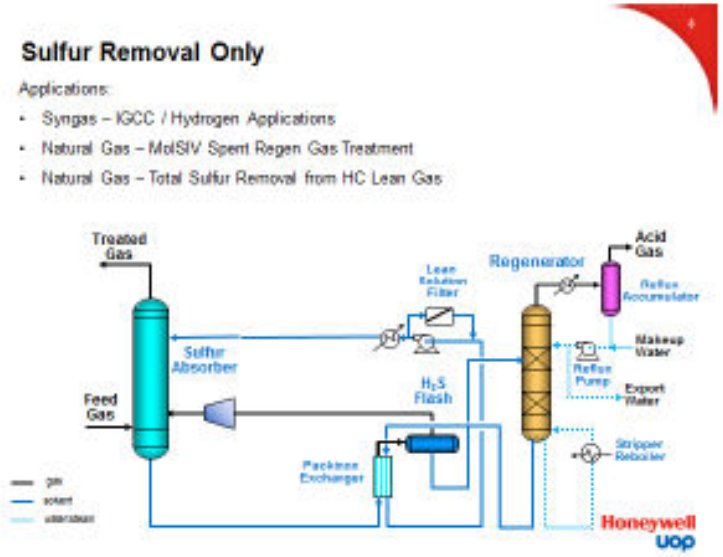
HON technology is capturing >38% of world's captured CO_2

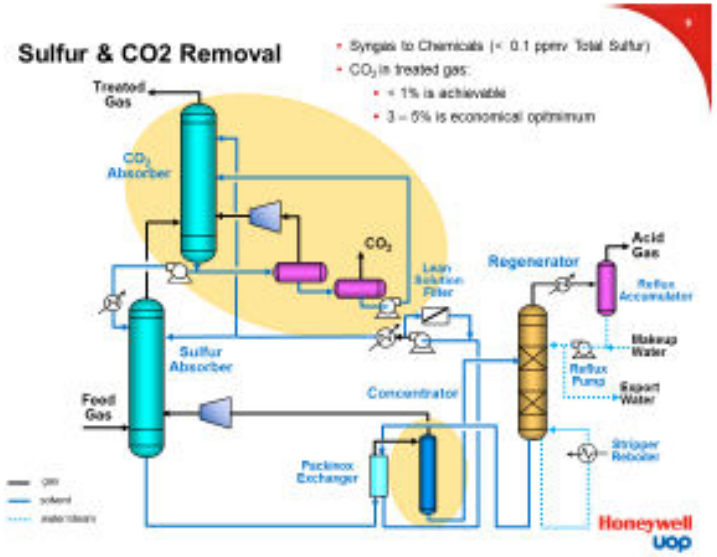
>40Mt CO_2 installed capacity; capturing >15 Mt per year

Source: Annual CO2 capture: IHSM Carbon Sequestration Projects Database;

SEPARALL –Physical Solvent Process

- Licensed Technology
- UOP next-generation Selexol Process
- DOW's family of SELEXOL solvents = dimethyl ethers of polyethylene glycol (DEPG)
- Physical absorption = no chemical reaction & energy efficient regeneration
- Solvent = 100% organic, bio-degradeable and non-toxic
- Two examples of schemes applied in syngas service (other schemes possible):





HONEYWELL CONFIDENTIAL

UOP Acid Gas Removal Technology in Gasification Plants

Plant	Start-up	Application	Production	Feedstock
Sarlux IGCC Italy	2000	Power H2 Production	550 MW net 40000 Nm³/h	Visbreaker Residue
API IGCC Italy	1999	Power	250 MW net	Visbreaker Residue
Coffeyville Resources USA	2000	Ammonia Urea	21 T/h 62 T/h	Petcoke
OPTI Canada Canada	2008	H2 Production & Fuel Gas	337,000 Nm³/h syngas	Asphaltene Residue
Duke Energy IGCC USA	2012	Power	approx. 600 MW net	Coal
Osaki CoolGen IGCC Japan	2019	Power	approx. 166 MW net	Coal

COFFEYVILLE RESOURCES (US) –Chemicals

Coffeyville Plant

45 ton/hr of Petroleum Coke

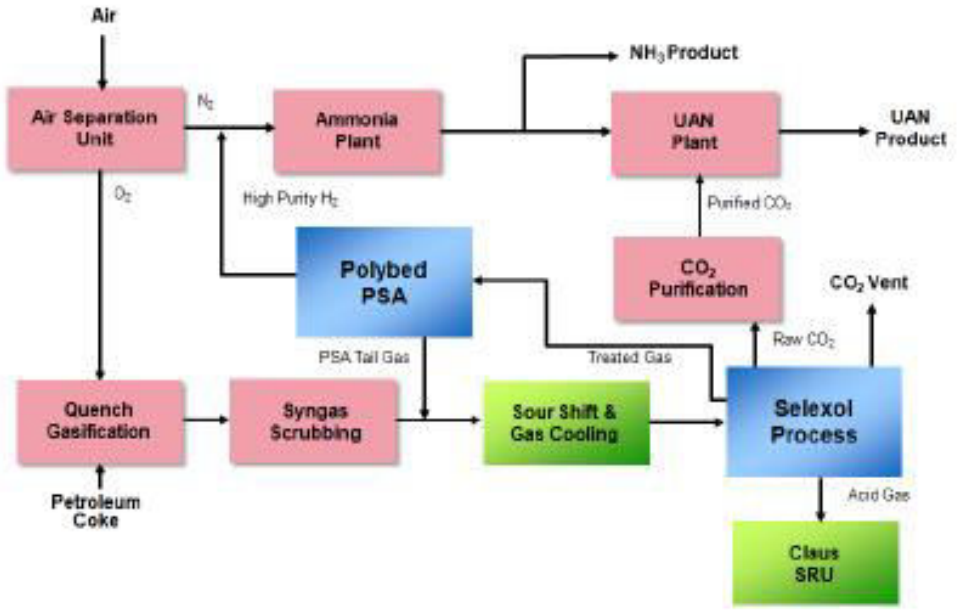
converted to 169,000 Nm^3/hr of Syngas

21 ton/hr Ammonia & 65 ton/hr Urea

UOP Technologies

Selexol Process (Sulfur & CO_2 Removal)

Polybed PSA (H_2 Purification)



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National Centre of Excellence in Carbon Capture and Utilization

सत्यमेव जयते
Department of Science and Technology
Ministry of Science and Technology
Government of India

XPRIZE CARBON REMOVAL | MUSK FOUNDATION

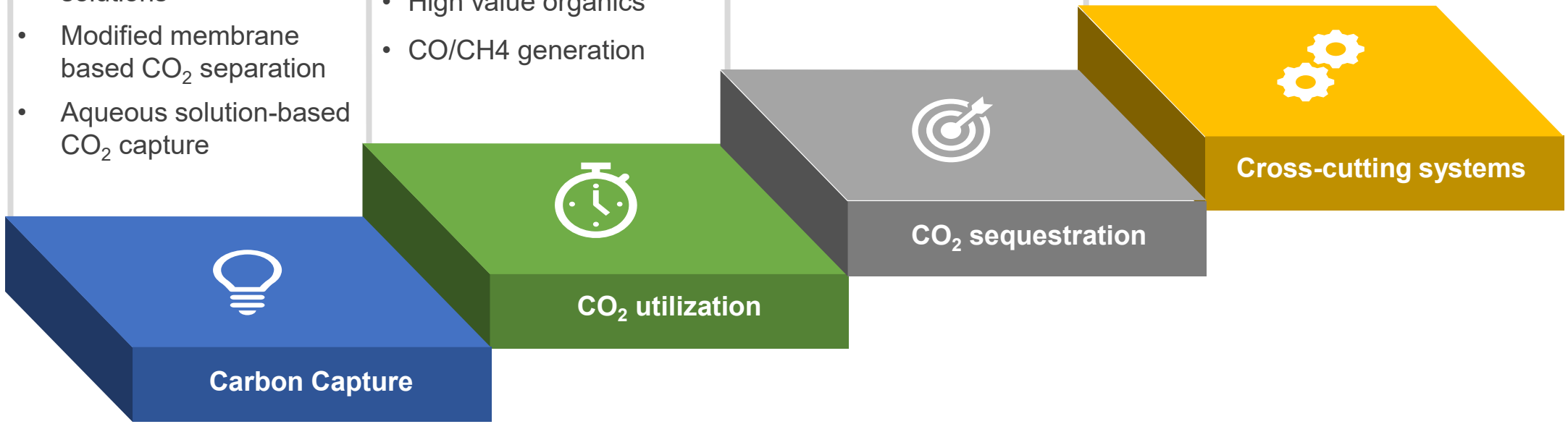
MISSION INNOVATION

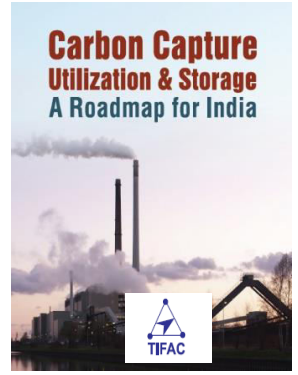
- Nanofluid amine based solutions
- Modified membrane based CO_2 separation
- Aqueous solution-based CO_2 capture

- CO_2 valorization
- Methanol production
- High value organics
- CO/CH4 generation

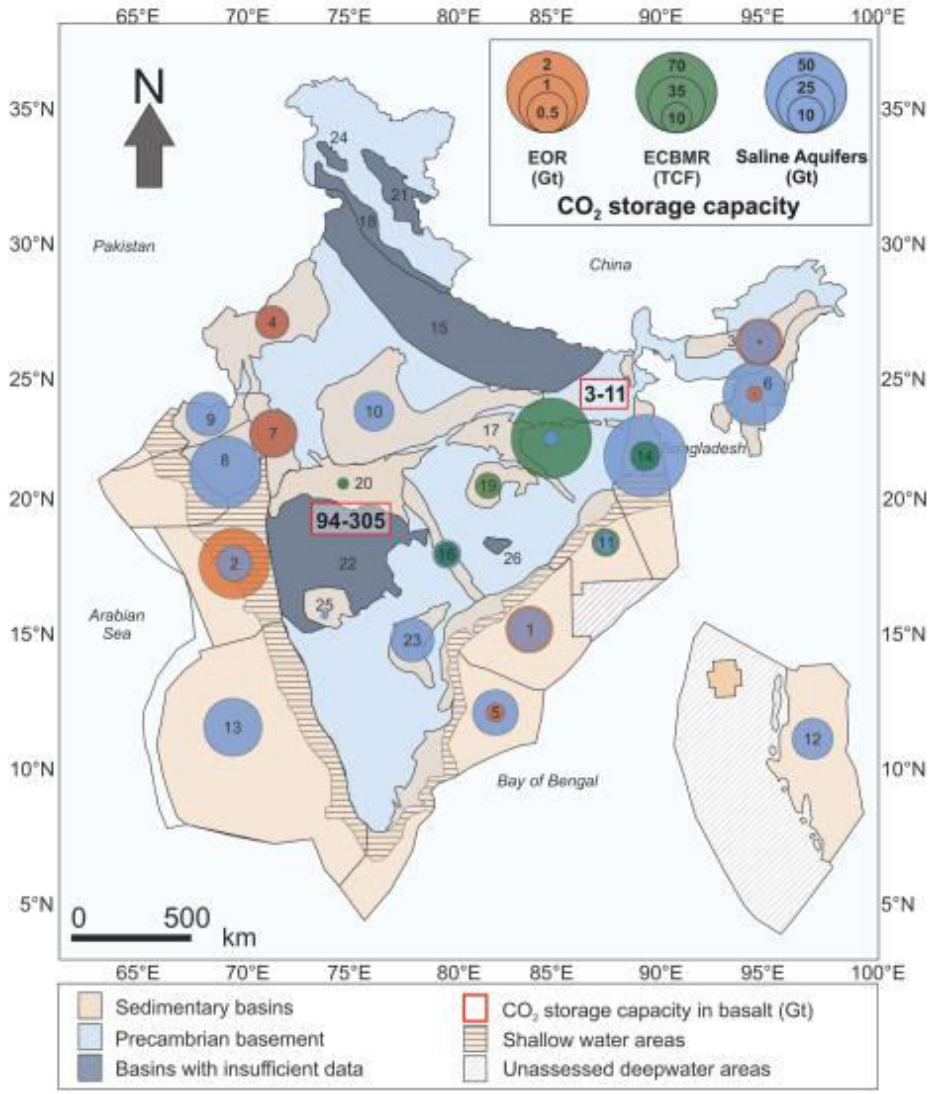
- Country-wide capacity assessment
- Enhanced oil recovery
- Enhanced CBM recovery
- Mineralization

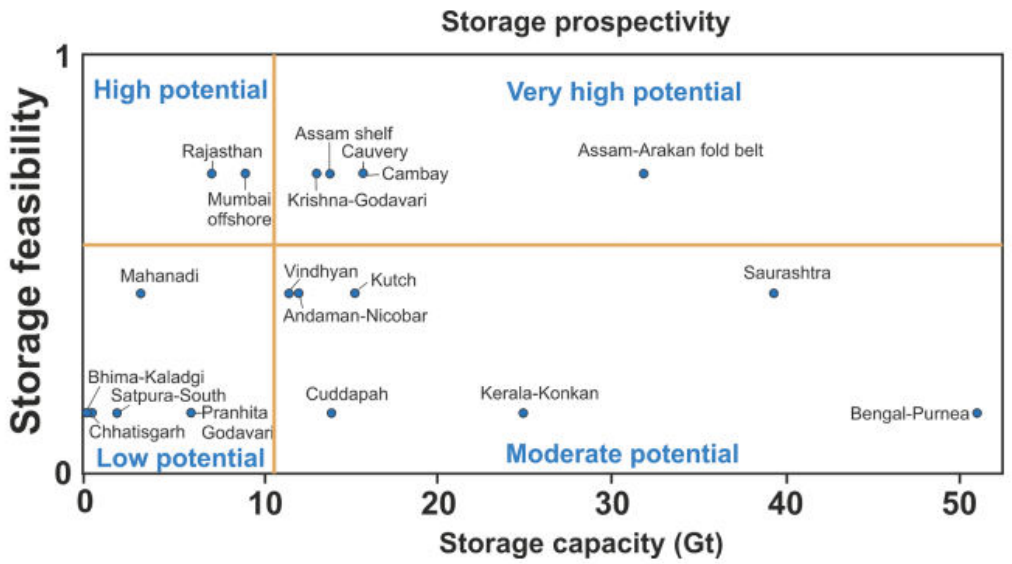
- CO_2 transportation
- Life-cycle analysis
- Techno-economic analysis
- Bioenergy based CCS (BECCS)
- Environmental Impact Assessment





CO_2 Storage Potential through CO_2 EOR, ECBMR, in Saline Aquifers, and in Basalt





Category-I basins	Category-II basins	Category-III basins
Reserves	Contingent Resources	Prospective Resources
1. Krishna-Godavari	8. Saurashtra	13. Kerala-Konkan
2. Mumbai Offshore	9. Kutch	14. Bengal-Purnea
3. Assam-Shelf	10. Vindhyan	15. Ganga-Punjab
4. Rajasthan	11. Mahanadi	16. Pranhita-Godavari
5. Cauvery	12. Andaman	17. Satpura-South Rewa-Damodar
6. Assam-Arakan Fold belt		18. Himalayan Foreland
7. Cambay		19. Chhattishgarh
		20. Narmada
		21. Spiti-Zanskar
		22. Deccan Syncline
		23. Cuddapah
		24. Karewa
		25. Bhima-Kaladgi
		26. Bastar

Source: A systematic capacity assessment and classification of geologic CO2 storage systems in India, Vikram Vishal et al

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Advanced Resources International

Our history of services:

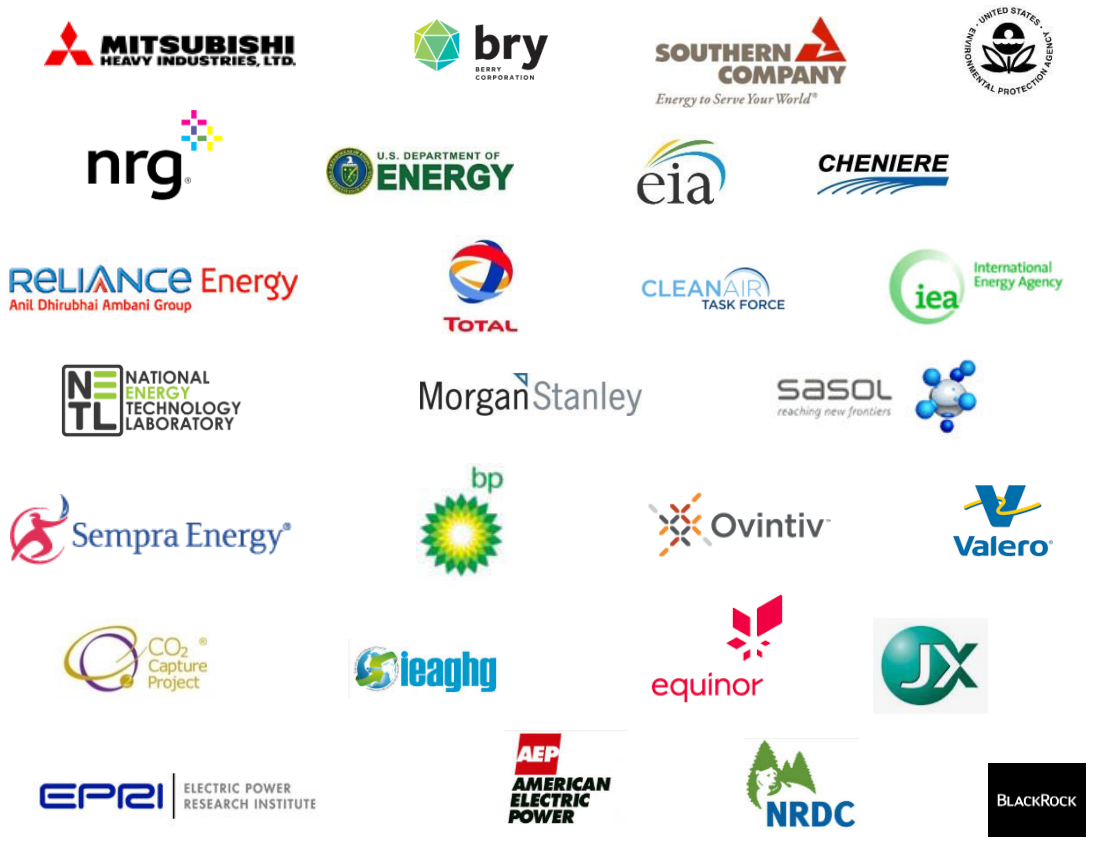
We specialize in the geological storage of CO_2, enhanced oil and gas recovery, and unconventional oil & gas resources.

Our approach is to integrate geology and geophysics, petroleum engineering, and strategic and economic analysis.

For over fifty years*, we have added value to hundreds of oil and gas E&P projects in the U.S. and in over 30 countries, from Australia to Zimbabwe.

*From 1971 – 1987, the company was called Lewin & Associates; from 1987 – 1991, the company was a subsidiary of ICF Consulting/Kaiser Engineers; since 1991, the company is stand alone and called Advanced Resources International, Inc.

Our clients include:



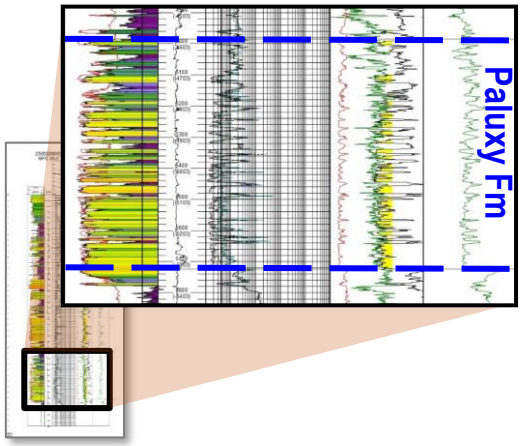
CCUS Project Expertise

Advanced Resources International, Inc.

Flagship CCUS Project

Kemper County Project ECO$_2$S: Ph II/III CarbonSAFE - CO$_2$ Storage and Utilization

For the U.S. DOE ECO$_2$S (Early CO$_2$ Storage) Project, ARI, as the geology and engineering contractor, is managing the drilling of the six project characterization wells, collection and interpretation of geologic data, modeling, and UIC Class VI permitting.



Source: Mississippi Power Company

Mississippi Power | SOUTHERN COMPANY Energy to Serve Your World℠ | Advanced Resources International, Inc. | U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

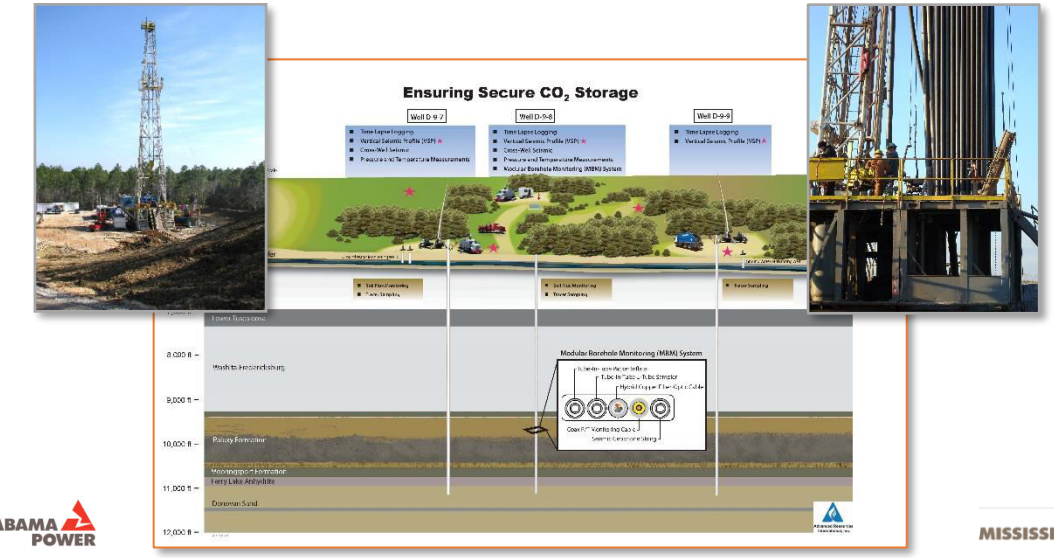
Notable CCUS Field Projects

Citronelle Carbon Dioxide Capture and Storage Project

Advanced Resources provided the project design and reservoir modeling, field installation and operating support, and the monitoring function to SECARB/EPRI/ Southern Company for the integrated CCS project at Citronelle.

Plant Daniel CO$_2$ Injection Test

Advanced Resources was the principal project director, geological and reservoir managers for SECARB's CO$_2$ injection project at Plant Daniel, MS.



ALABAMA POWER | MISSISSIPPI POWER | Denbury | U.S. DEPARTMENT OF ENERGY | SECARB Southeast Regional Carbon Sequestration Partnership | NATIONAL ENERGY TECHNOLOGY LABORATORY | EPRI ELECTRIC POWER RESEARCH INSTITUTE | Advanced Resources International, Inc. | SOUTHERN STATES ENERGY BOARD

Enhanced Oil Recovery Expertise

Advanced Resources International, Inc.

World-Wide Technology Leader in CO_2-EOR – Studies and Projects

ELSEVIER

GHGT-11

CO_2 Utilization from "Next Generation" CO_2 Enhanced Oil Recovery Technology

Vello A. Kuuskraa, Michael L. Godec, Phil DiPietro

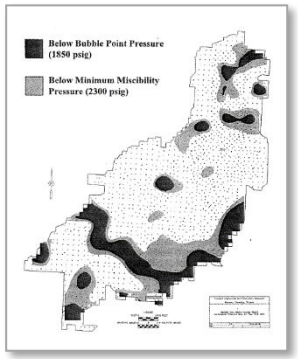
Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO_2-EOR Recovery

U.S. DEPARTMENT OF ENERGY

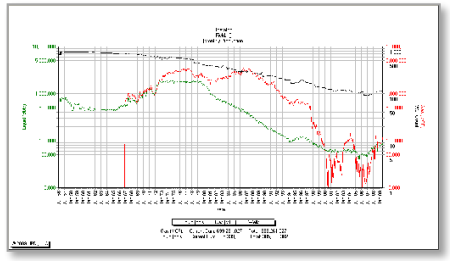
SACROC Oil Field (West Texas). ARI assessed the feasibility of applying gravity-stable CO_2 flooding in the SACROC field, one of the largest CO_2-EOR projects in the world.

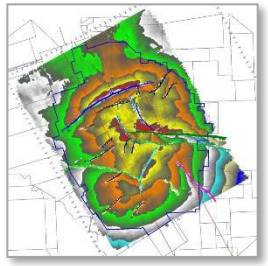
The project involved: (1) integration of 3D seismic, borehole logs and core data, (2) building a high-resolution geologic and reservoir model, and (3) conducting detailed reservoir simulations to evaluate the performance of the CO_2 flood.

SACROC Pressure Contour Map

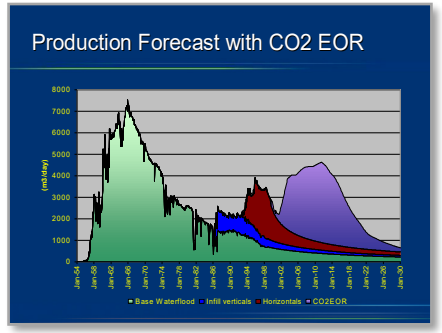


Conroe Oil Field (East Texas). ARI conducted a reservoir modeling-based evaluation study of the giant 2.2-billion-barrel Conroe Oil Field for a private client. The study involved evaluating the efficiency of applying WAG (water-alternating-gas) vs. straight CO_2 injection for EOR.





Weyburn Field (Canada). ARI completed a major project for EnCana (now Ovintiv) on the Weyburn field in Saskatchewan, the largest CO_2 flood in Canada. The project involved detailed reservoir simulation to analyze performance and identify opportunities for improving the CO_2-EOR flood.



At the conclusion of the three-year project, the Weyburn Business Unit received the award as the best performing business unit within EnCana (now Ovintiv).

Clients and Projects in India

Advanced Resources International, Inc.

Overview of Major Projects: India

Feasibility studies conducted jointly with India companies and US TDA.

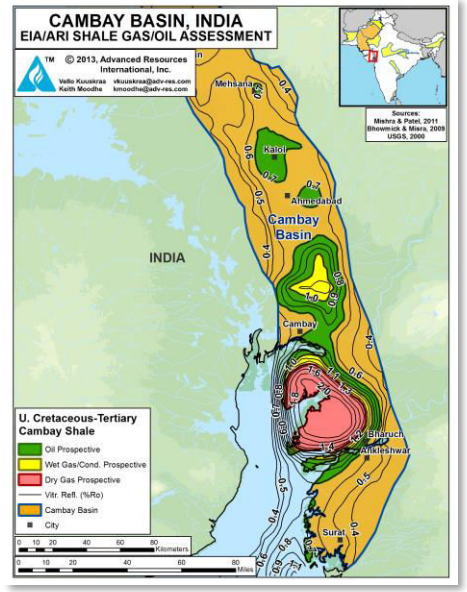
USTDA United States Trade and Development Agency

Technical And Economic Feasibility Study For Coalbed Methane Development In North Gujarat, India, (2003)

ESSAR OIL

Technical And Economic Feasibility Study For CBM Development Of the Sohagpur E and W Blocks In Madhya Pradesh, India, (2008)

Reliance Industries Limited



ARI performed a World Shale Gas and Shale Oil Resource Assessment including India supported by US EIA.

eia

Joint projects with India Ministry of Coal, Coal India and US EPA.

Coal India

Methane to Markets

Global Methane Initiative

United States Environmental Protection Agency

Overview of Major Clients: India

Over the past 25+ years, we have worked on numerous private and public projects in India for companies such as Reliance, ONGC, and ESSAR.

Reliance Industries Limited

ओएनजीसी ONGC

ESSAR

Empowering India · Nurturing Nature · Enabling Life · Coal India

cmpdi A Mini Ratna Company

PRABHA Energy Private Limited

GAIL

GAIL (India) Limited

Back

Blue Planet: About the Company

- **Blue Planet Ltd** 2012 (Cayman Islands) – Now **Blue Planet Systems Corporation** (Delaware)
- Financing to date: Equity & Venture Debt
  - Mitsubishi Corp., Chevron, Knife River (MDU Resources), Kamine Development Corporation
- **San Francisco Bay Aggregates LLC (SFBA) -** is Blue Planet's first commercial plant project
  - Demonstrate larger scale commercial operation - Currently at Pilot stage
  - Financed independently from Blue Planet

What's unique about the Blue Planet approach…

- **Less cost & energy** - Does not require pure CO_2
- **CO2 is permanently sequestered** – In carbonate minerals
- **Products sold at a profit** – Aggregates for use in concrete
- **Not dependent on subsidies for CO_2 abatement**
- **Massive and growing market for aggregate products** – Construction aggregates is the largest volume opportunity for CO_2 utilization
  - ✓ 56G tons/yr of aggregates consumed world-wide with 6%/yr growth
  - ✓ If that was all synthetic Limestone that would equal 24.6G tons/yr of captured/sequestered CO_2

Technology/Expertise Overview

Flue Gas or other CO_2 sources
(no minimum % CO_2)

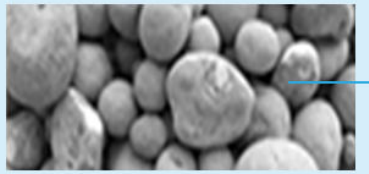
Obtain CO_2 Component

Waste Concrete
Or
Other Industrial Wastes (Fly Ash, Slag, CKD, BR, etc..)

Obtain CaO (and/or MgO) Component

Carbon mineralization

~44% by mass CO_2



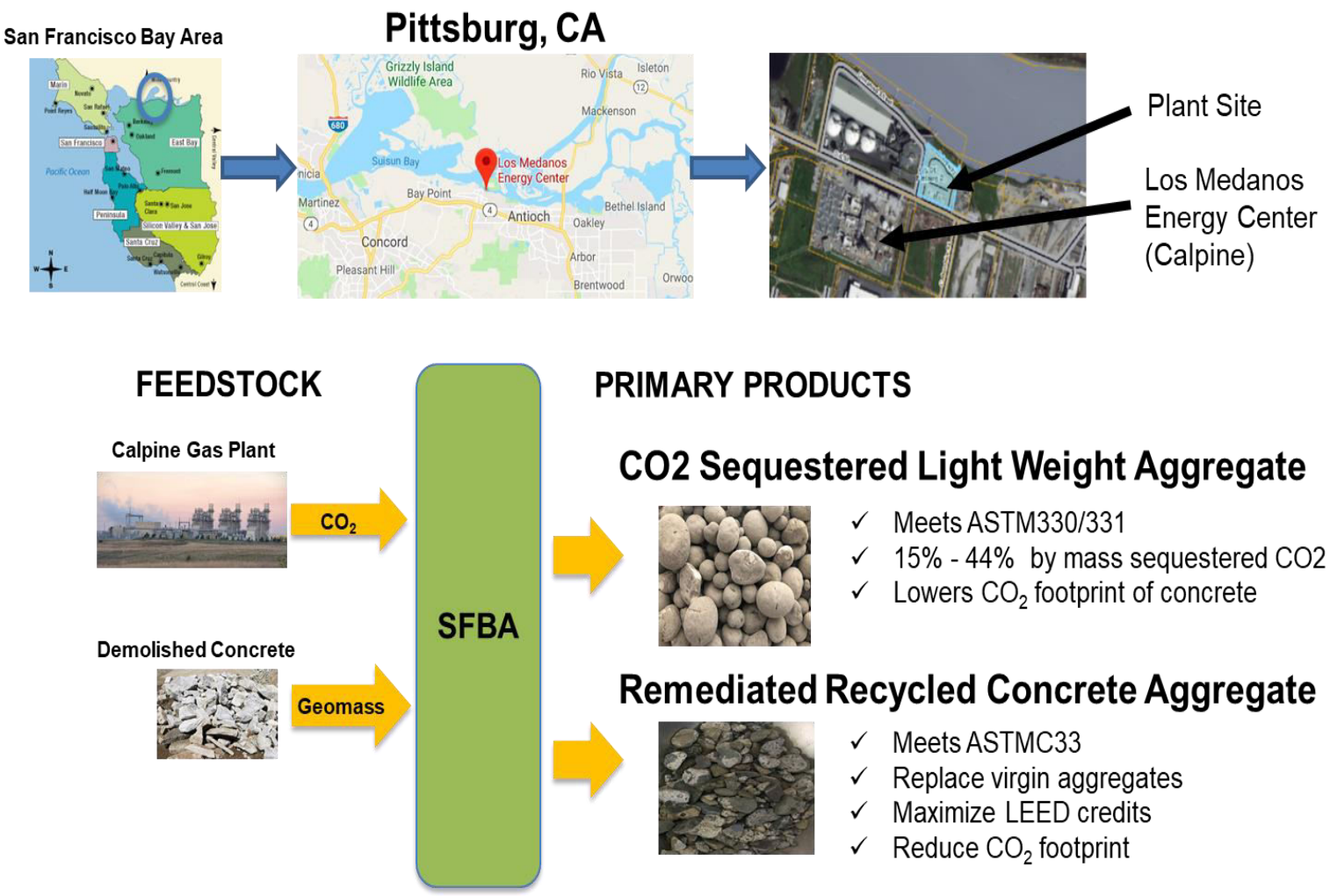
Limestone Aggregates

Concrete or other construction projects

Original sand & gravel

Clean Recycled Concrete Aggregates

Reference Projects



<u>San Francisco Bay Aggregates</u>

4Q21 – Engineering Pilot

3Q22 – Production Pilot

2023 – 2024 Production Ramp to 175K tonne/yr of CO_2

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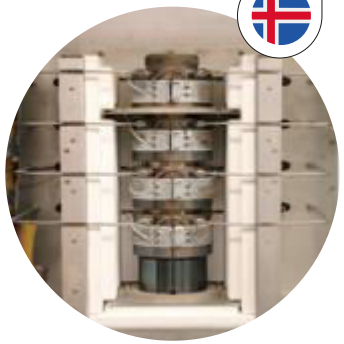
10+ Years of Leadership Advantage in Technology & Operations

CARBON RECYCLING INTERNATIONAL

Pilot → **Industrial demonstration and R&D** → **Commercialization**

2006 - 2011 | 2012 - 2014 | 2015 - 2017 | 2018 - 2020 | 2022 | 2024



kg per day

First CO2-to-methanol pilot plant

1,3 ktpa

First industrial e-methanol plant

4 ktpa

Largest industrial e-methanol plant to date

0,4 ktpa

Adaptation to wind energy, steel furnace gas

No other company has yet delivered +1 ktpa plant

2 x ≥ 100 ktpa

Full scale utilizing hydrogen byproduct

#1 Recycled carbon project worldwide

100 ktpa

Largest electrolysis hub and e-methanol plant

#1 E-methanol at scale - worldwide

Pipeline of commercial projects

Patented Process Converting Waste CO2 into Sustainable Methanol

Inputs → **Process** → **Globally traded methanol**

Recycling CO2 from **emissions**

Recover stranded H_2 from **industry**

or

Generate green H_2 by **electrolysis**

Methanol

Green chemicals feedstock
Versatile replacement for fossil alcohols and hydrocarbons

Fossil fuel replacement
Methanol is a highly efficient fuel and releases no sulphur or soot

CRI's business model is selling Emissions-to-Liquids technology and services

CARBON RECYCLING INTERNATIONAL
carbonrecycling.is

CRI industry leader with first renewable methanol plant

George Olah Plant, Svartsengi, Iceland

Client: Carbon Recycling International
Capacity: 4000 tons/year (5,040,000 litres)

Innovations

- ✓ Emissions-to-Liquids industrial demonstration
- ✓ First CO_2 hydrogenation plant
- ✓ Megawatt-scale electrolysis
- ✓ Kiloton-scale CO_2 utilization
- ✓ Low-turndown synthesis
- ✓ Optimized for CO_2-rich syngas

CARBON RECYCLING INTERNATIONAL
carbonrecycling.is

First commercial scale ETL plant in China - start of commissioning mid 2022

Shunli Plant, Anyang, Henan, China

Client: Henan Shuncheng Group
Capacity: 110,000 tons/year (140 million litres)

Innovations
- ✓ Direct CO_2 hydrogenation with coke-oven gas
- ✓ Capture from lime kiln

CARBON RECYCLING INTERNATIONAL
carbonrecycling.is

Second commercial scale ETL project in China - start of engineering in 2021

Jaingsu Sailboat, Lianyungang, Jiangsu, China

Client: Jiangsu Sailboat Petrochemicals
Capacity: 100,000 tons/year (125 million litres)

Innovations

- ✓ Conversion of H_2 from propane dehydrogenation unit (PDH)
- ✓ CO_2 CCU from ethylene oxide/ethylene glycol process

CARBON RECYCLING INTERNATIONAL
carbonrecycling.is

Commercial scale e-methanol plant – start of operations in 2024

Finnfjord, Norway

Partners: Statkraft, Finnfjord smeltverk
Capacity: 100,000 tons/year (126 million litres)

Innovations
- ✓ 120 megawatts electrolysis
- ✓ 150,000 tons CO_2 recycling
- ✓ Capture from FeSi process

Statkraft

FINNFJORD

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