KBR Energy Solutions

ECCJ
The Energy Conservation Center, Japan

Agenda

Presentation

Decarbonisation Renewable Energy CO_2 Capture CCUS	45 minutes
K-SAAT	15 minutes
Plastic Recycling	20 minutes
QPinch	20 minutes
Energy Efficiency & Industry Trends	20 minutes

Proud history, bright future.

Example Elements - Health and Safety Monitoring Solution - Features

NOISE LEVEL DETECTION

Readings from various sensors, sound level meters - ambient sounds, vibrations, engines, turbines, pressure valves, etc… Monitoring, alerts provided if threshold levels exceeded.

AIR QUALITY DETECTION

Gas sensors located around a plant, sensors in tags & helmets - capable of detecting the level of various gases (ex: H_2S, CH_4, Carbon Monoxide, Methane, isobutene, +) Monitoring, alerts provided if threshold levels exceeded.

INTELLIGENT INTERACTIVE SYSTEM

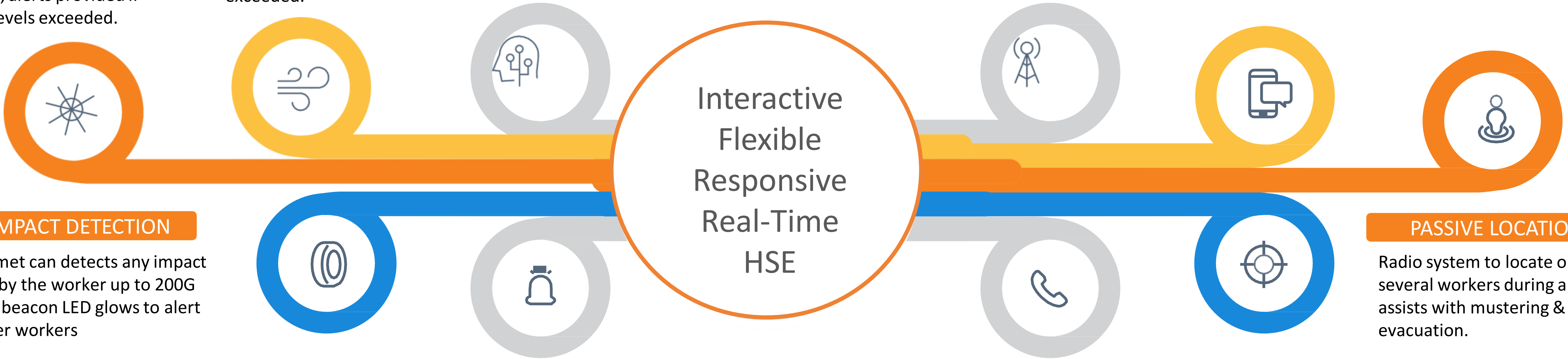
If the operator does not inform of a possible danger, the intelligent interactive system takes decision with integrity and security

ACTIVE LOCATION RADIO/ FIBRE

System to locate and monitor workers in real-time – Wi-Fi, UWB, BLE, Cellular, Satellite, +

COMMUNICATION BY TEXT MESSAGE

Information and alert messages can be sent to workers in any location through text messages via phone, personnel tag or hard hat



IMPACT DETECTION

Helmet can detects any impact felt by the worker up to 200G and beacon LED glows to alert other workers

PASSIVE LOCATION

Radio system to locate one or several workers during an event, assists with mustering & evacuation.

MOTION DETECTION

Detects if a worker is immobile for a predefined time and alerts if a worker remains still or has fainted. Accelerometer can also be leveraged to show rapid descent/movements, indicating a potentially dangerous event.

SOS SWITCH

Worker can seek immediate attention in case of emergency by pressing panic button

EMERGENCY CALL

Hands-free voice communication by making voice call to emergency number and receive calls from any number

ACTIVE GPS TRACKING

Locate the actual position of the worker in both outdoor and indoor locations

KBR at a Glance

Revenue *Full year 2018*	Headquarters	Employees	Global Presence
$4.9 B	**Houston** Texas	**37,500+**	**80+** Countries

KBR works closely with government and industry clients to provide purposeful and comprehensive solutions with an emphasis on efficiency and safety. With a full portfolio of services, proprietary technologies and expertise, we handle projects and missions throughout their entire lifecycle, from planning and design to sustainability and maintenance.

KBR's View of Decarbonisation

The aim of a Decarbonisation Strategy Plan is to support decision making to meet current and future CO_2 reduction challenges.

This means proactively defining operating and structural changes needed to sustain competitive advantage into the future.

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KBR's View of Decarbonisation

Fuel / Feedstock Decarbonisation

- Total elimination of liquid fuel firing
- Pure H_2 (zero carbon) emissions as fuel
- H_2 recovery options from waste/ fuel gas
- H_2 generation options from import natural gas
- **Green H_2 options / H_2 based chemical production**
- Surplus H_2 monetization as an export product / transport fuel
- **Recycled plastic** as feedstock
- Renewable feedstock (HVO) feedstock

Power Decarbonisation

- **Integration of renewable energy** sources

Social Impact Integration

- Understand country-wise and Global incentives associated with industrial decarbonisation activities
- Identify potential decarbonisation initiatives favoured by the country's strategy that benefit the synergy between the business and the community
- Community and social involvement during the decarbonisation process

Advanced Energy Efficiency Solutions

- **Low grade heat recovery**
- 'Cold' energy (e.g. on LNG vaporisation)
- District heating/cooling
- Real-time fuel / steam / power optimisation
- Data analytics and visualization / **Remote monitoring**

Real-time Carbon Measurement

- Measurements, on-line analysis
- Data analytics and visualisation

Carbon Capture and Re-use

- **Methanol and methanol to olefins**
- Methanol to animal feed protein
- Enhanced oil recovery
- Concrete applications
- Specialist in high purity applications (medical, food)

Asset Portfolio Rationalization

- System-wide production / distribution model (linear program)
- Relative carbon intensity of operations by site
- Carbon upgrade value by site, per tonne of product
- Alternative *reduced carbon* European supply chain options
- Development of site-by-site strategic CO_2 reduction roadmap – operational rationalisation / improvement, capital investment
- Regional investment subsidies and tax incentives

Inter-site synergies

- Over-the-fence utility supply / sharing

Strategic Electrification

- Switch from steam to electrical drivers for key rotating equipment items
- Variable speed drives
- Electric heaters / hot oil loops
- Impact on site-wide fuel / steam / power balance

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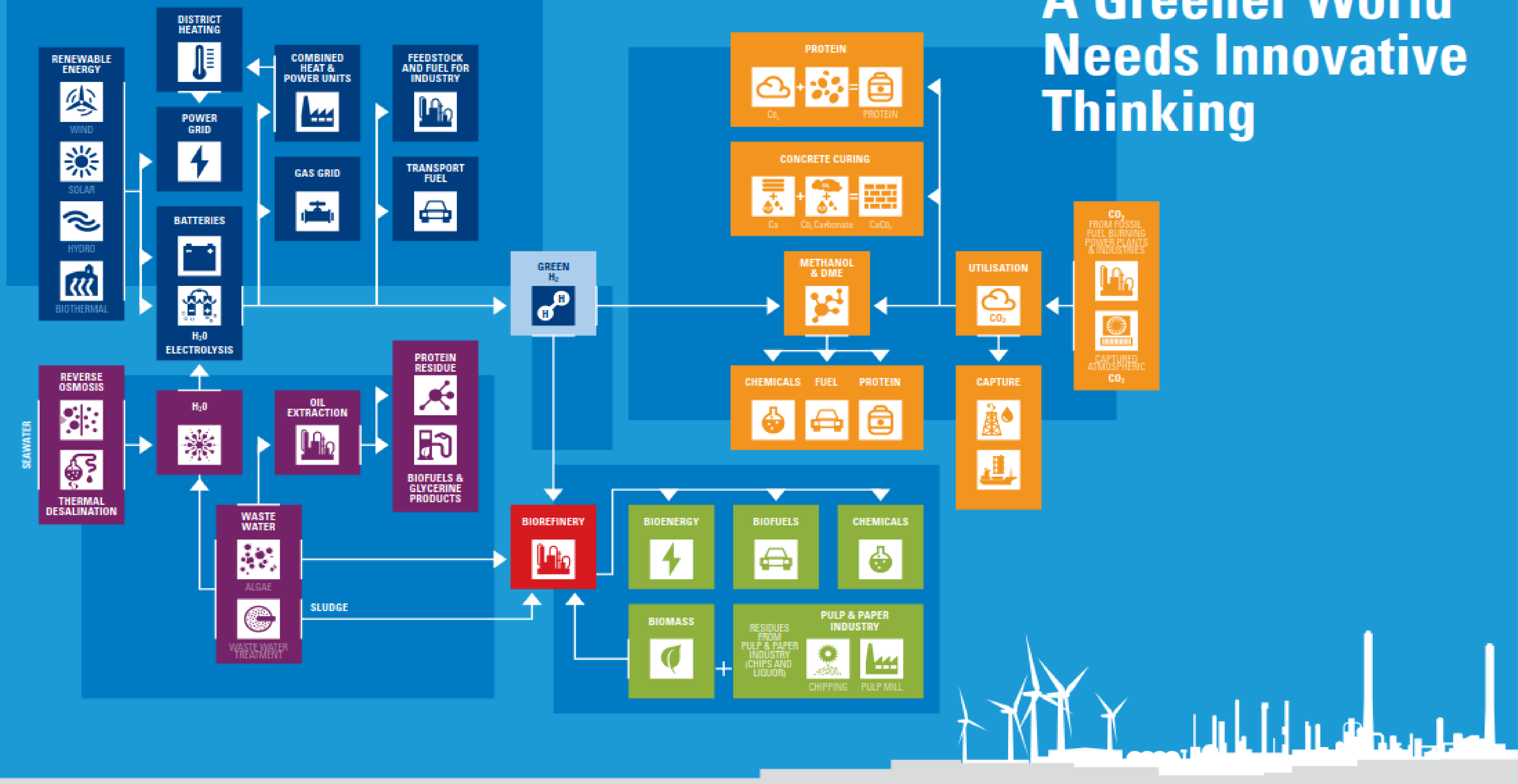
A Greener World Needs Innovative Thinking



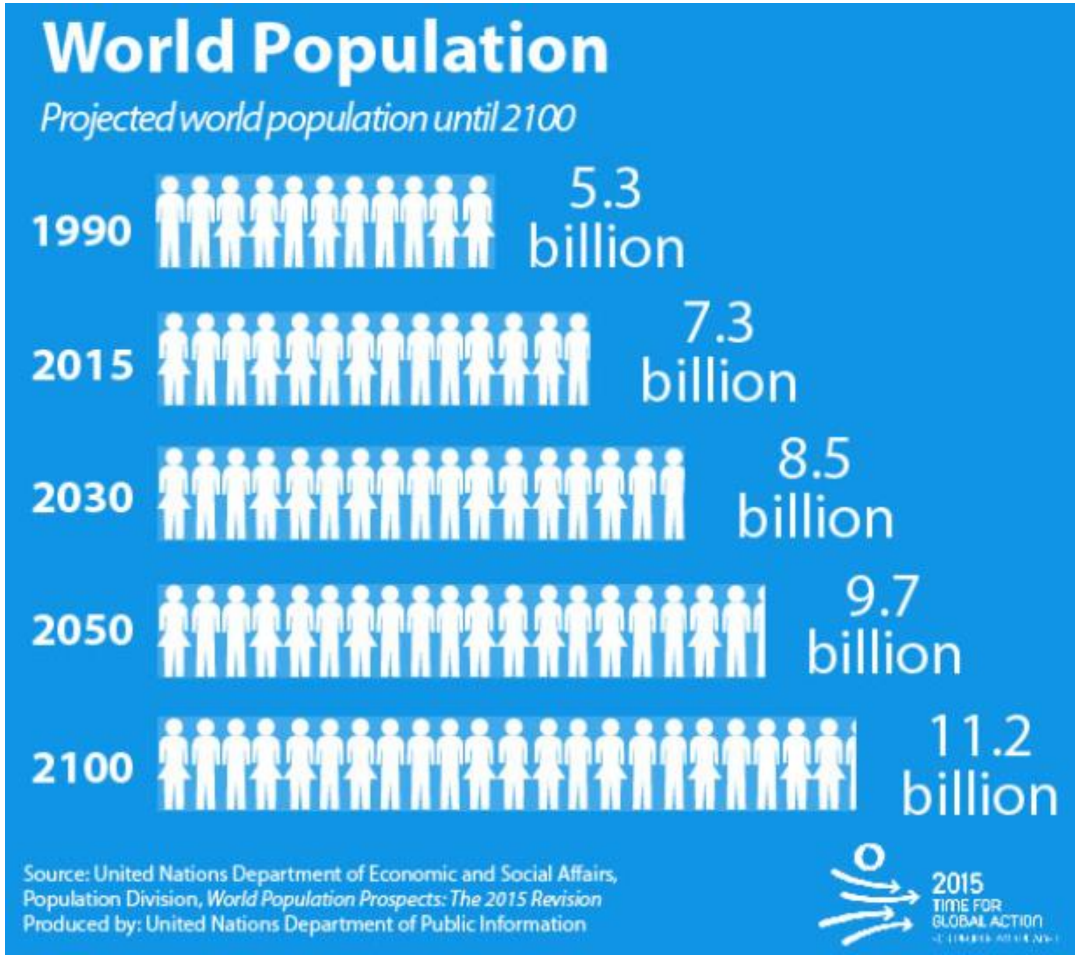
Renewables in the Petrochemical Industry

Renewable Energy

CO_2 Capture

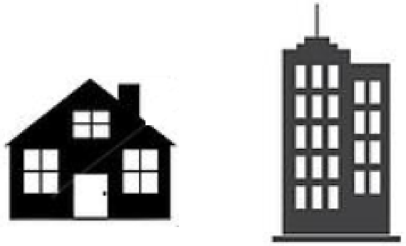
CCUS

The Challenge: Growth in Population



About 60% of global population live in Asia

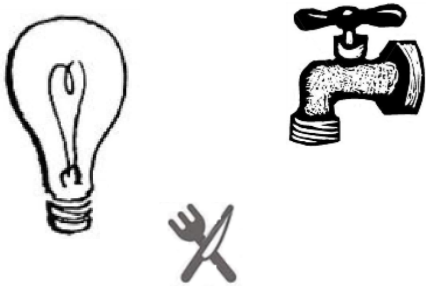
This will lead to an increase demand on :



Facilities & Infrastructure

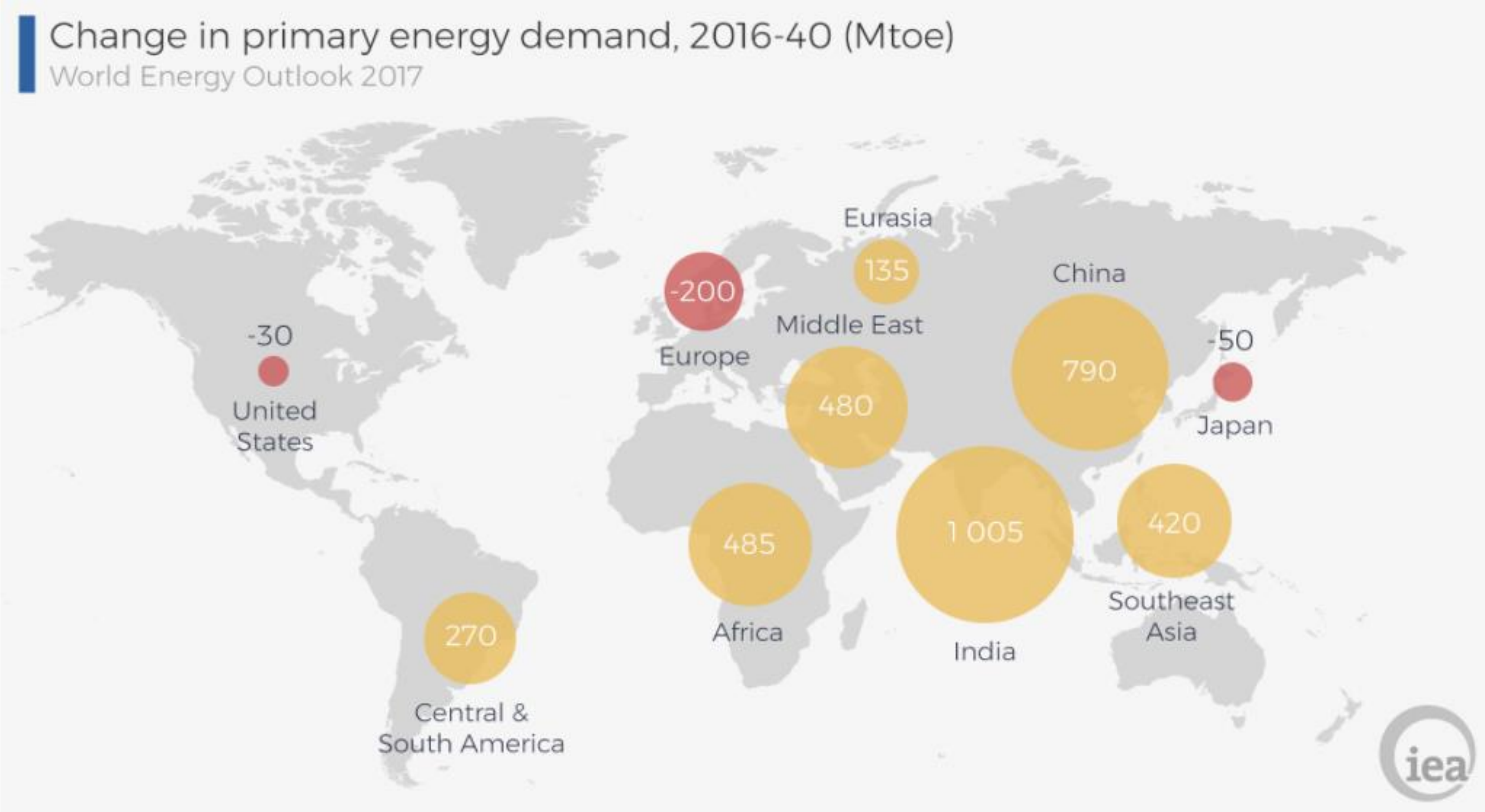
Transportation

Resources



The Challenge: Fulfill Energy Demand

IEA forecast energy consumption will **increase by ~30% by 2040**



This is the equivalent of adding another China and India to today's global demand

Energy Transition

Period of significant change

Public sentiment

Das Emissions.

Renewables at parity with fossil fuels

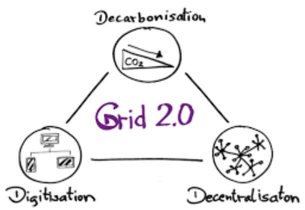
Energy majors wading into new markets

Statoil equinor

Energy transition

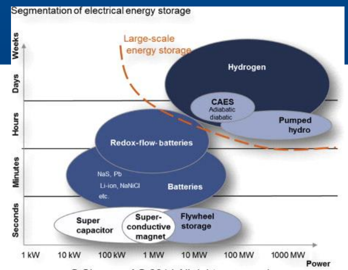
Economics – reduced need for govt incentives

Energy decentralization



Increased regulation

Energy vector storage



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Global Cost trends

The reduction globally in the capital costs of solar panels, wind turbines and electrolysers is making green Hydrogen projects attractive investments.

Solar power cost

2009
$350 / MW hour

2019
$30 / MW hour

Wind power cost

2013
$180 / MW hour

2018
$60 / MW hour

Electrolyser investment cost

2016 / 17
$1.8 million / MW

2019
$0.3 million / MW

Disruption

When technologies make possible to create new markets and destroy or radically transform existing ones

No Longer Business as Usual as World Looking for a Path to Decarbonisation

- G7 supporting cutting greenhouse gases by 40% - **70% by 2050 from 2010 levels and phasing out fossil fuels use by end of century**
- Paris Agreement aims to limit global warming to well below 2°C and **achieve net zero emissions this century**
- **Norway Sovereign Wealth Fund withdrawing investments from mining or energy groups deriving more than 30% of sales or activities from coal business**

equinor

- **2018 Statoil becomes Equinor**
- **Investing in the renewables market**
  - ✓ 2017 enter partnership with Norway's Scatec Solar
  - ✓ 40% Equity in Scatec's Apodi solar power plant
  - ✓ 2018 announced talks to partner with Petrobras for offshore wind power

DONG energy / Ørsted

Exiting its legacy **oil and gas** business **to focus on** wind turbines and **clean energy**

lightsource bp

Since 2010, one of the largest solar companies in the world based on installed capacity

- ✓ £2.5Billion invested into solar assets over the last 7 years
- ✓ 2.0 GW of solar projects

REPSOL

- Repsol wants to become known as an energy company, rather than an oil producer
- Actively investing in the wind power sector
- In 2018 joint forces with Enagás to produce hydrogen from solar energy

Shell Hydrogen newmotion

- **Supporting H2 as society's energy vector**
  - ✓ First H2 fueling station opend in 2017 – target 400 by 2023
  - ✓ The REFHYNE project: 10MW green H2 facility in Rhineland Refinery
- Shell invests in New Motion Charging
- $2Bn Shell Alt Energy

TOTAL

Investing across sectors:

- Solar PV and other renewable enterprises
  - ✓ Solar Star (California) one of the world's largest photovoltaic power plants
  - ✓ 2018 acquired 100% stake in Dracena I/II/IV photovoltaic solar plant
  - ✓ MoU with Petrobras for onshore solar and wind in Brazil (2018)
- Battery producers
- Oil and gas assets from Maersk (US$7.5bn)

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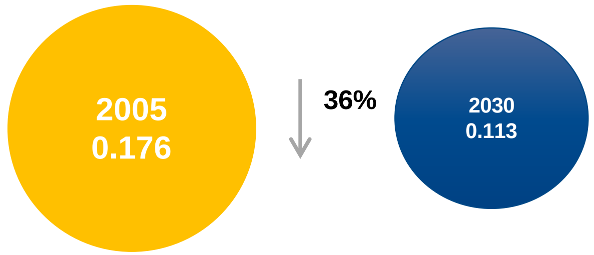
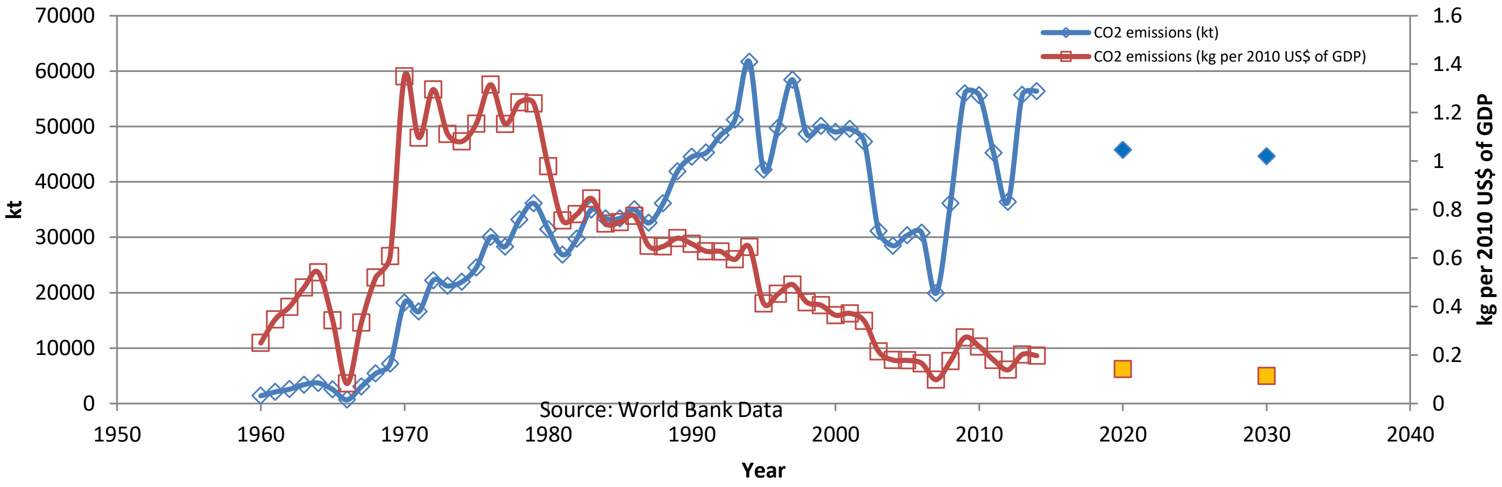
Singapore Context

Singapore's Emission Intensity (kgCO2e/S$GDP)





Key factors

Nat Gas based power generation emits: 62.2% (2010 data)

Fuel Oil based power gen / ethylene crackers: 36.0% (2010 data)

Changing fuel mix for power gen. (2017): 95.2% based on NG; (Total : 5300 MWh)

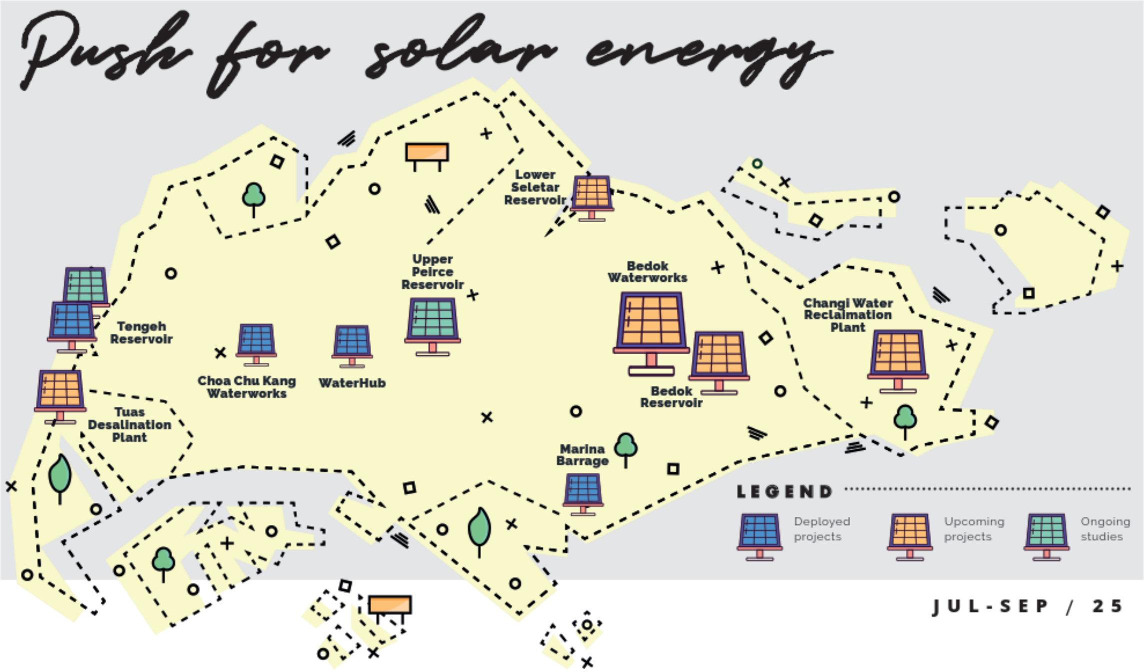
Solar PV increasing but only nominally: <100 MWh (installed capacity ; 2017)

Data shows that carbon capture is needed on top of energy efficiency & renewables initiatives to achieved the established targets

Renewable Energy Options in Singapore

Renewable energy options are limited in Singapore

- No hydro resources
- Wind speeds and mean tidal range are low
- Geothermal energy is not economically viable
- **Solar energy** remains the most viable renewable energy



✓ 350MWp by 2020
✓ Beyond 2020: 1GW-peak
✓ Land is limited – floating solar (in reservoirs) is piloted and commissioned

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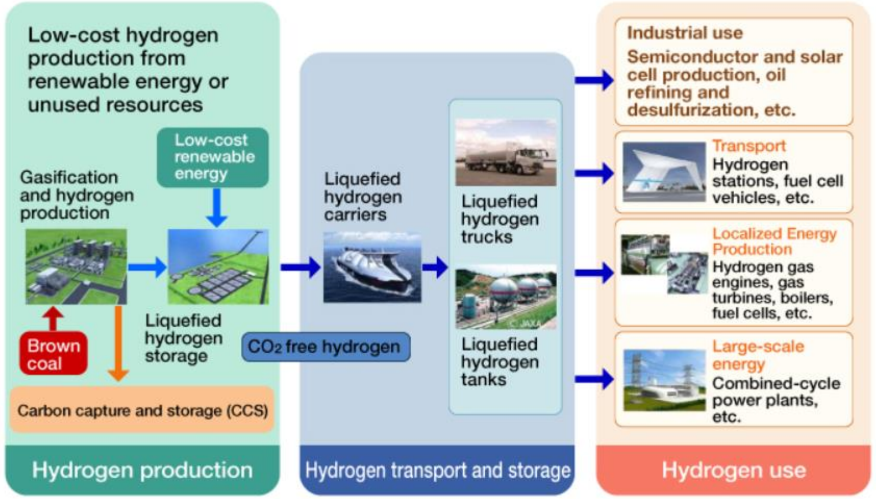
Renewable Energy Options in Singapore (cont'd)

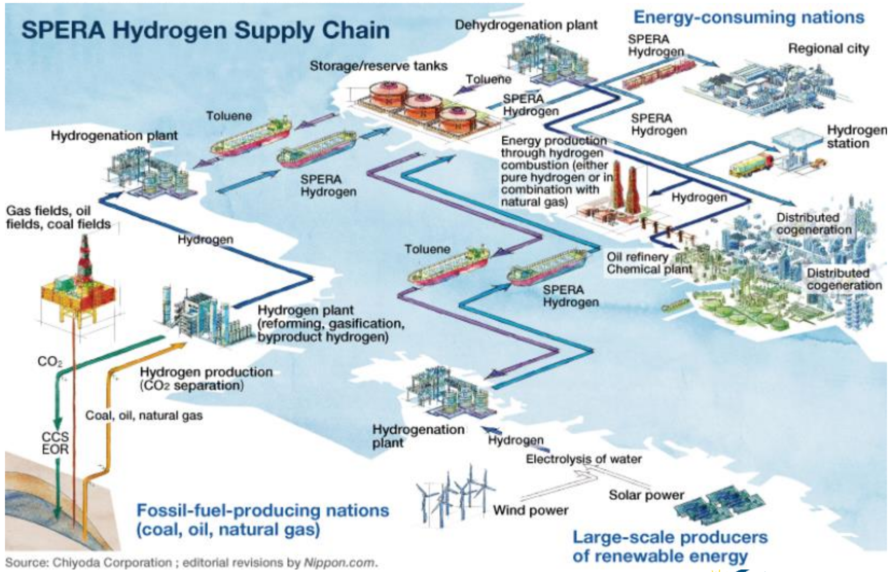
Other considerations:

- Floating solar
  - ✓ Ocean Sun Norway has developed large scale offshore solar installations
  - ✓ Pilot installation in place

- Road solar
  - ✓ Under development as issues on efficiency and safety concerns

- Build green H2 installations abroad, in locations where renewable energy and land are plentiful, and import it
  - ✓ Either as H2, NH3, MCH, etc





Source: Chiyoda Corporation ; editorial revisions by *Nippon.com*.

Storage was the Main Challenge for Renewable Energy

CHALLENGES

- Sufficient plot space
- Function of the climatic conditions
- **STORAGE**

The Options

- Flow batteries
  - ✓ Fuel cell that also runs in reverse—essentially converting energy back into chemical reactants—the resulting flow battery could store solar power using inexpensive, organic fuel
- Hydrogen & NH_3
  - ✓ Water is just broken it into its elemental form, then hydrogen is stored and then burn when required
- CO_2 utilisation
  - ✓ Using solar energy to convert carbon dioxide into useful chemicals
- Salts for solar
  - ✓ Molten salt can absorb extremely high temperatures without changing state
  - ✓ Test shows 17 hours of energy in reserve
  - ✓ Licensors: GE, Abengoa

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Battery Usage in Heavy Industry

Guidelines and any other info

- Batteries can be used to improve the energy efficiency of plants with multiple Gas Turbines (GT) by allowing operating less number of GT at an increase the load
- For instance in systems with multiple GTs, they run at part load in parallel such that if one Gas Turbine trips, the other Gas Turbines can quickly increase the capacity to meet the demand
- Using batteries reduces the requirement to have all Gas Turbines operational at part load and allows at least one to be on cold standby
- Should one of the Gas Turbines trip, the battery will be able to supply enough power for enough time to allow the stand-by Gas Turbines to be switched to an operational mode from cold
- This configuration increases the efficiency of the plant significantly

KBR References

Browse FPSO Concept / Define – Woodside AUS.
Confidential client – Small Scale LNG Concept application.

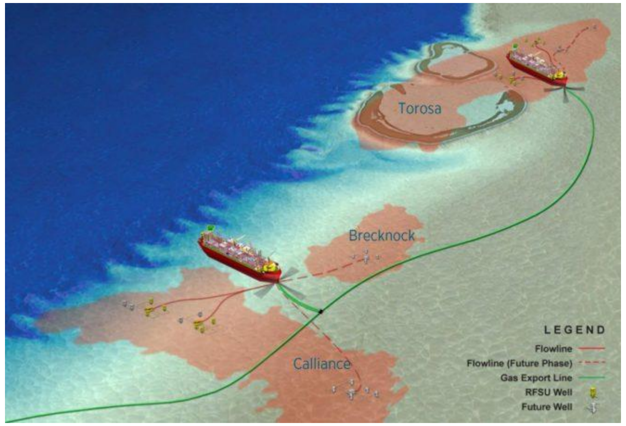

ABB PowerStore Battery

Scalable Lithium-ion battery for industrial energy storage applications

Woodside Goodwyn A platform - AUS
Installation of 1 MWh battery solution enabling Woodside to switch off half of the small gas generators & decommission one unit

Tesla PowerPack

Scalable Lithium-ion battery for industrial energy storage applications

- South Australia 100 MW / 129 MWh energy storage system - 2017
- Southern California Edison 20 MW / 80 MWh Peaker plant replacement – 2016
- Kauai Island, HI 13 MW / 52 MWh, Solar Energy firming and shifting - 2017

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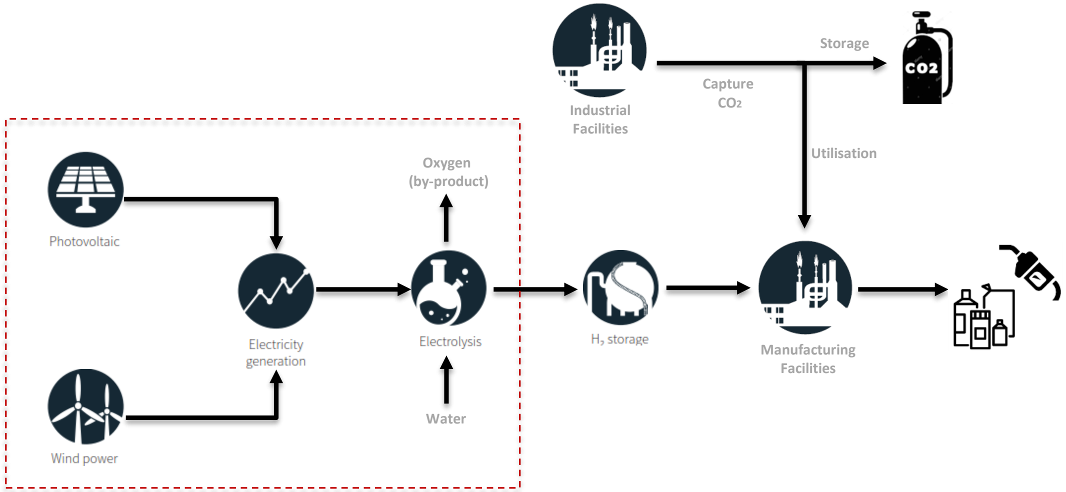
Hydrogen is Key for the Energy Transition

- When burned to produce heat or reacted with air in a fuel cell to produce electricity, the only by-product is water
- Decarbonisation of gas distribution networks
  - ✓ Use hydrogen as a heating fuel either blended with natural gas or neat
- Replace of carbon based fuels for cars
  - ✓ Use hydrogen in electric cars or buses in conjunction with a fuel cell
  - ✓ Fuel cells are efficient than the internal combustion engines
  - ✓ Potential issues related to H2 storage on vehicles but alternatives are analysed (e.g. via ammonia)
- Useful as a way to store renewable energy from intermittent sources

- Currently, 96% of hydrogen generation is derived from fossil fuels
  - ✓ Which generates additional CO2
  - ✓ Sources: 49% natural gas, 29% followed by liquid hydrocarbons and 18% from coal
- And about 4% from water electrolysis
  - ✓ No CO2 footprint as long as power is generated by renewables



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Current H_2 Market

- An estimated 69.1 million metric tons of hydrogen consumed in 2017
- Largest volumes of intentionally produced or merchant hydrogen are consumed at refineries, in ammonia production, and in methanol
- Most of this hydrogen is produced by the consumer at the site where it will be used
- Fuel cell applications in the automotive sector are a fast-growing segment for hydrogen, with plenty of potential ramping up in the near future
- Main Sector using H2 in APAC:

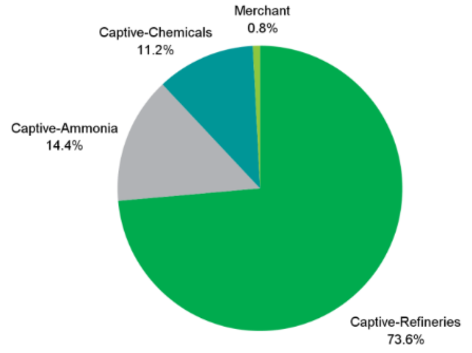
✓ Japan: 74% of total consumption is from the captive refinery market

✓ China: NH3, methanol and refining - China is the world's largest hydrogen producer and consumer, accounting for about 30.9% of total world consumption

✓ Southwest Asia: Ammonia industry is the largest hydrogen consumer, with 64% of total consumption in 2017. The refinery industry is second with 35%

2017 Japan H2 Market

Total = 11.7 kNm^3



Source: IHS

- Petroleum refining: 73.6%
- Ammonia production: 14.4%
- Merchant hydrogen: 0.8%

✓ Electronics, metal production, fats and oils and float glass

The commercial price of hydrogen for fuel cell vehicles at the hydrogen stations is set at \$ 8.9–9.8 per kg (excluding tax)

Not naturally occurring
95% SMR* Manufactured
Industry Captive

Global \$130Bn / year

Global Production 60M t/year (SMR)
500 Mega tonnes CO2

1 1s¹
H
Hydrogen
1,008

Hydrogen Council – estimate
Market **\$2.5T** (2050)
CO2 driven growth
Energy Carrier

Blue H2
SMR + CCS/CCUS

Green H2
Electrolysis

Cost of Renewable H_2 will have to be Competitive Against other H_2 Sources

The cost of hydrogen depends on process, feedstock and production capacity

- NG & Coal: USD 1 – 2 per kg[1]
  - ✓ Natural gas steam reforming is a mature technology with large-scale industrial plants in operation and a commercial efficiency ranging from 70 to 85%
  - ✓ Coal gasification is a less used and less efficient (50-70%) process
  - ✓ Carbon capture/storage is not included on the above values
- Renewable electricity: USD 3 – 5 per kg[1&2]
  - ✓ Commercial alkaline electrolysis : electricity-to-hydrogen efficiency of 62-82%
  - ✓ Cost is very sensitive to the electricity cost

Storage

- Compression energy amounts to 10-15% of the hydrogen energy content (up to 30% for very high pressure)
  - ✓ Cost is estimated to range between €0.9 and €1.75/kg[1]

Transportation

- Liquefaction absorbs between 30% and 40% of the energy content
  - ✓ €0.13-015/kg for liquid tankers[1]
  - ✓ 0.14-0.26/kg for pipeline and €0.5-0.6/kg for tube trailers (100 km)[1]

1. The Energy Technology Systems Analysis Program (ETSAP) from the International Energy Agency (IEA)
2. U.S. Department of Energy Office of Scientific and Technical Information

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Hydrogen Project Profiles

Hydrogen Fuel Cell Bus

- The scheme is set to deliver 144 hydrogen fuel cell buses and associated refueling infrastructure in nine cities and regions across Europe.
- Transport for London (TfL) has launched a tender for the bulk procurement of hydrogen fuel cell buses

H21 Program

- Unveiled plans that 3.7 million homes and 40,000 businesses and industries in the north of England that are heated by natural gas could be converted to hydrogen by 2034

Hydrogen Trains

- The design of a hydrogen-powered train for the UK market has been unveiled by Alstom and Eversholt Rail
- 'Breeze' will be a conversion of an existing Class 321 train
- The 'new' trains could run across the UK as early as 2022

MET Police

- London's Metropolitan Police Service has added 11 Toyota Mirai hydrogen fuel cell cars to its fleet
- The ambition of the MET is to procure 550 vehicles as zero or ultra-low emission by 2020

Port of Valencia

- Port of Valencia is set to launch the H2Ports pilot project to utilise hydrogen energy for carrying out operations at its container terminals.
- It will also support the decarbonisation of the port's logistics chain.

Refhyne

- Worlds largest Hydrogen electrolysis plant in Shell's Rhineland Refinery
- With a peak capacity of 10 megawatts the hydrogen will be used for the processing and upgrading of products at the refinery and explore other applications.

Hydrogen Mobility Australia

- Australia's vision is a hydrogen society built upon clean and renewable energy technology, including hydrogen powered transport

Tokyo 2020

- The government has called the 2020 Tokyo Olympics the "Hydrogen Olympics" and plans to demonstrate many kinds of hydrogen technologies during the event

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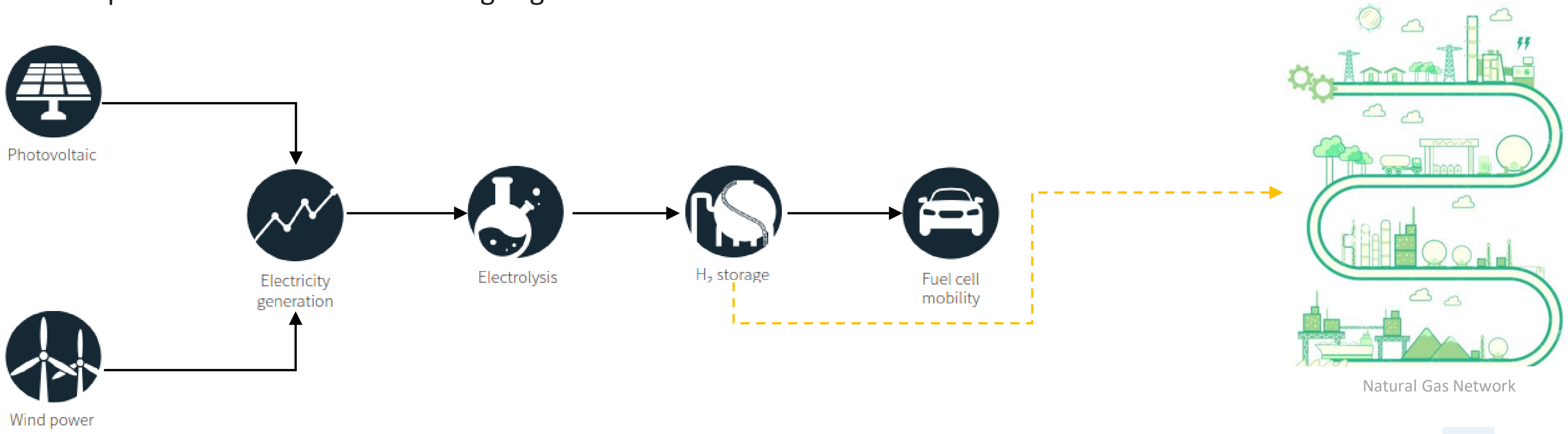
Hydrogen Project Profiles (cont'd)

EXAMPLE: H2 Injection to Gas Network

- Potential to blend hydrogen into the existing natural gas pipeline network
- Technically viable to implement with relatively low concentrations, less than 5%–15% hydrogen by volume

  - This ensures no significant risks associated with utilization of the gas blend in end-use devices.

  - Such as household appliances, overall public safety, or the durability and integrity of the existing natural gas pipeline network.
- In some urban areas, such as Germany, Netherlands, Hawaii, manufactured gas continues to be delivered with significant hydrogen blends and is used in heating and lighting applications as an economic alternative to natural gas
- This can help to decarbonise the natural gas grid



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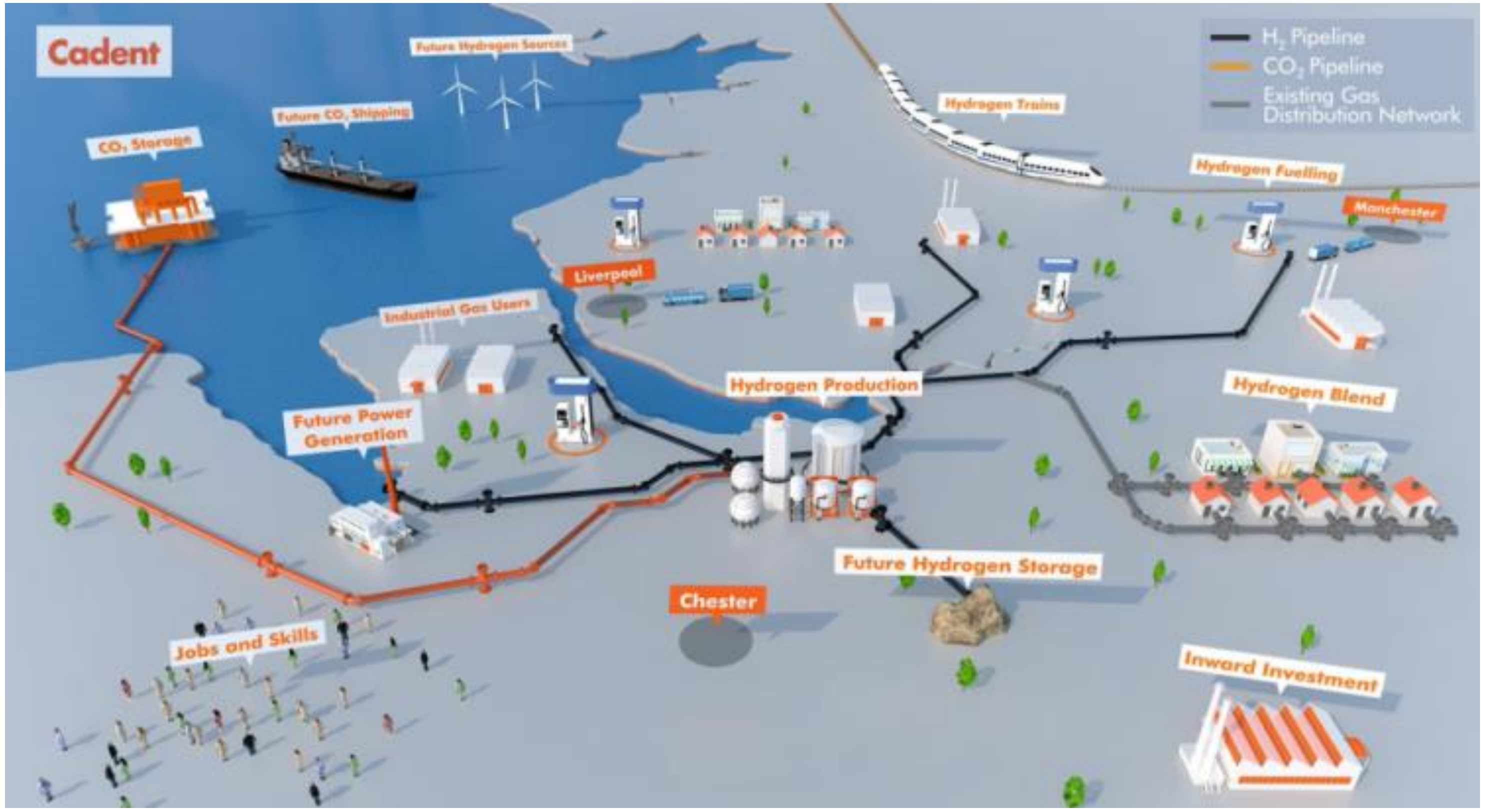
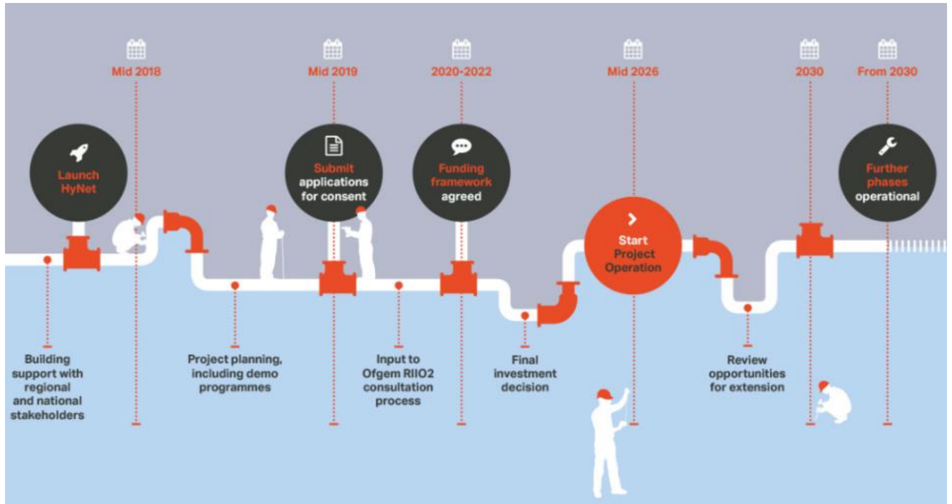
Hydrogen Project Profiles (cont'd)

EXAMPLE: H2 Injection to Gas Network





The HyNet Project – NorthWest England

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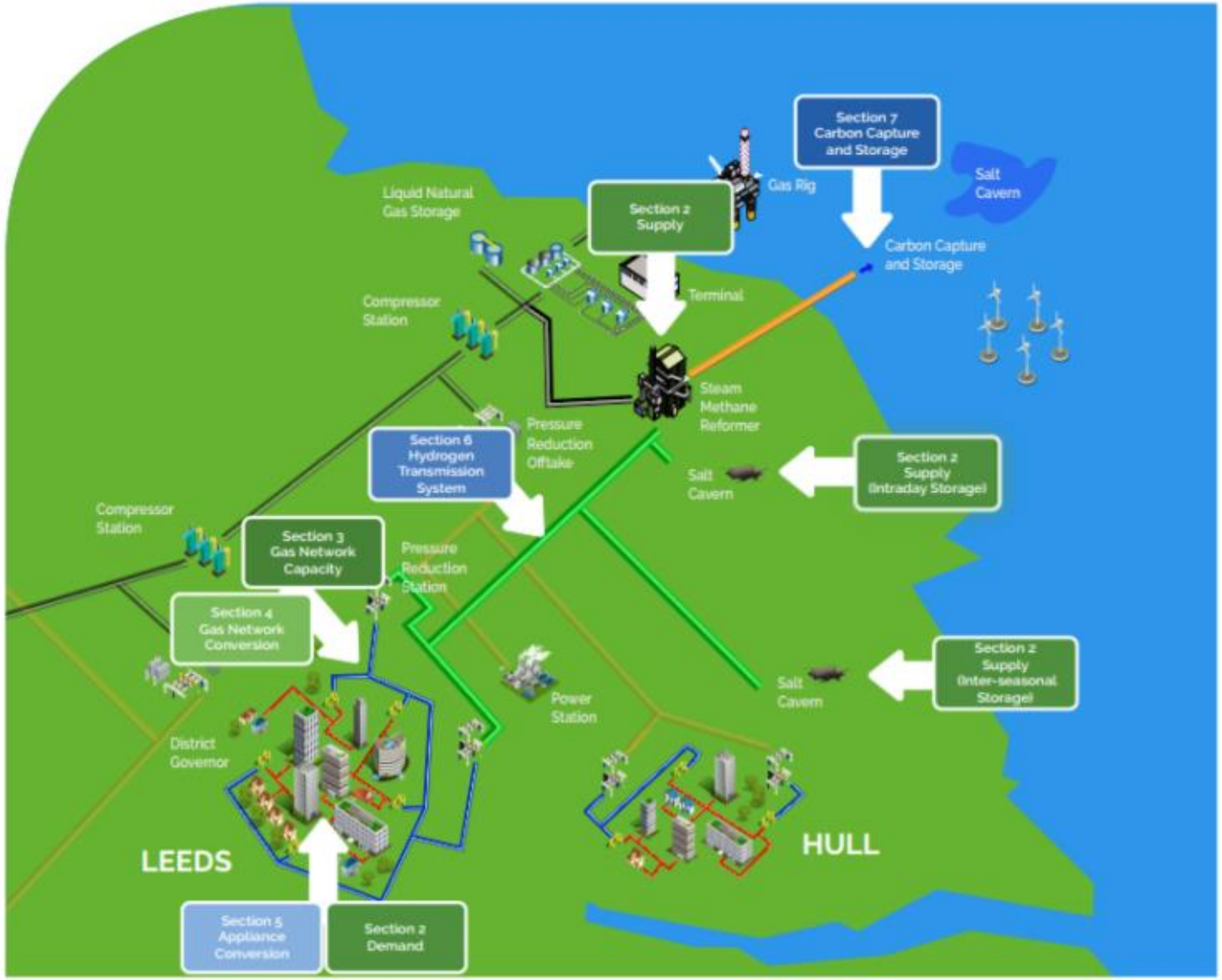
Hydrogen Project Profiles (cont'd)

EXAMPLE: H2 Injection to Gas Network

The H21 Leeds City Gate study



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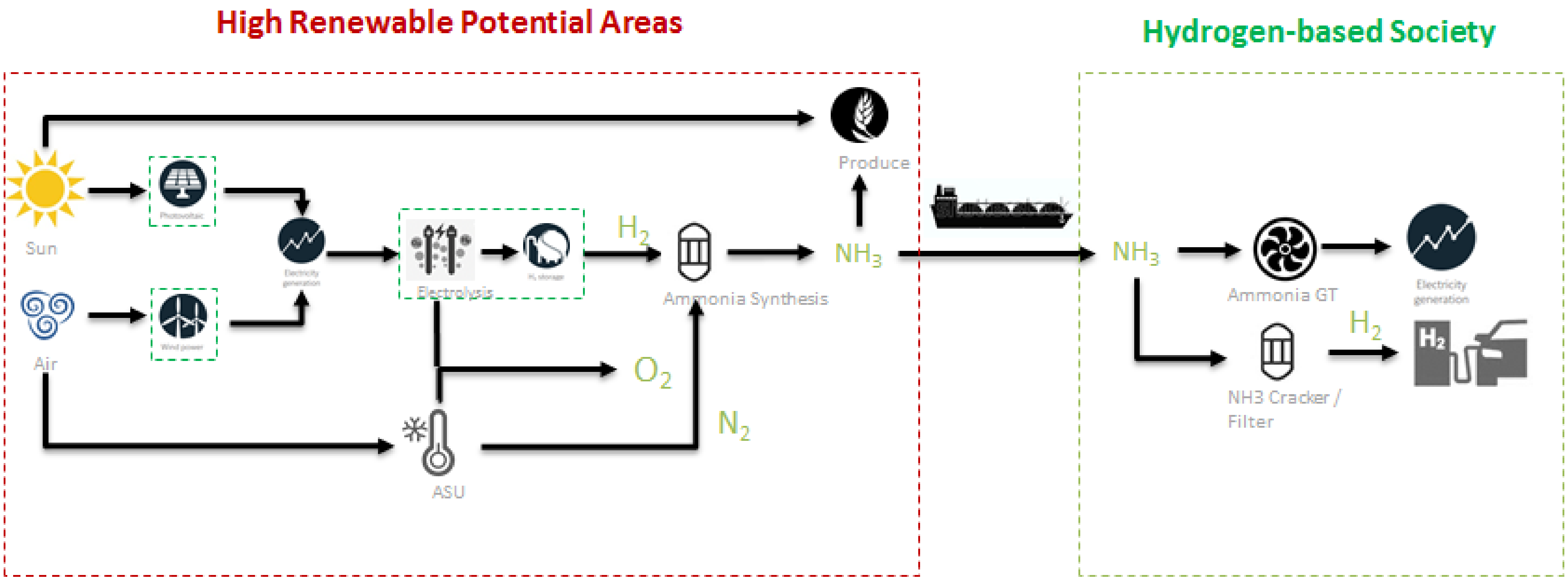
Hydrogen Project Profiles (cont'd)

EXAMPLE: H2 as energy vector



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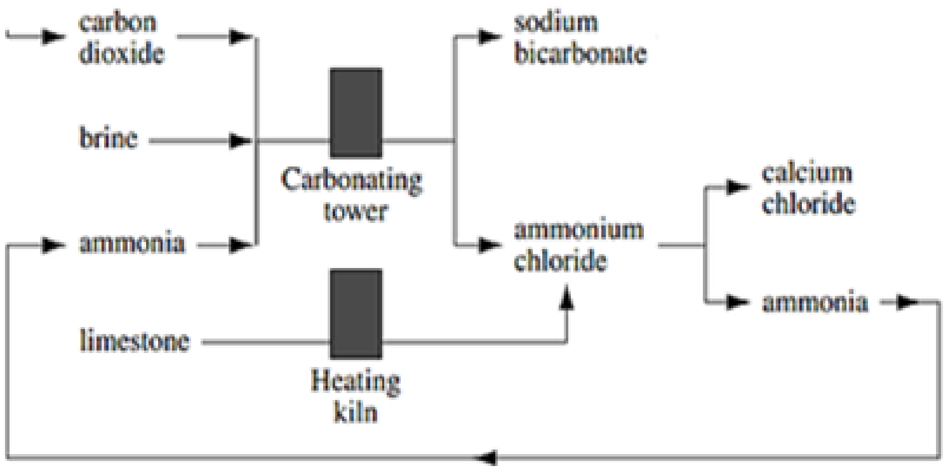
Potential Issues: Brine from Water Demineralization

- Water desalination will create significant amount of brine as by-product
- A possible solution is to combined with pure CO2 from CCS to produce Sodium Bicarbonate



- To 2021 world consumption of Sodium Bicarbonate is expected to continue to increase at a rate of about 2% per year
- The largest part of demand growth will be in Asian markets
- Sodium Bicarbonate Value USD 200 – 300 / tonne

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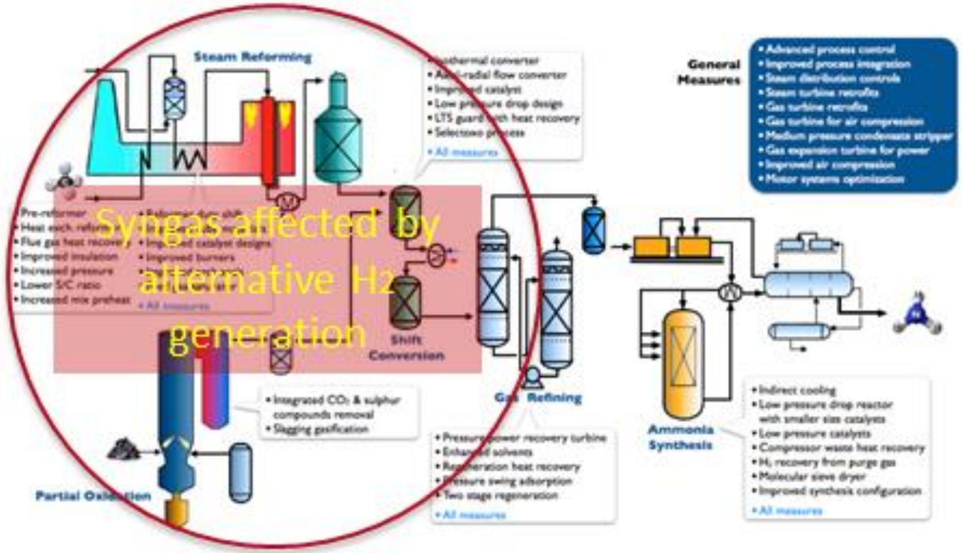
Green Ammonia

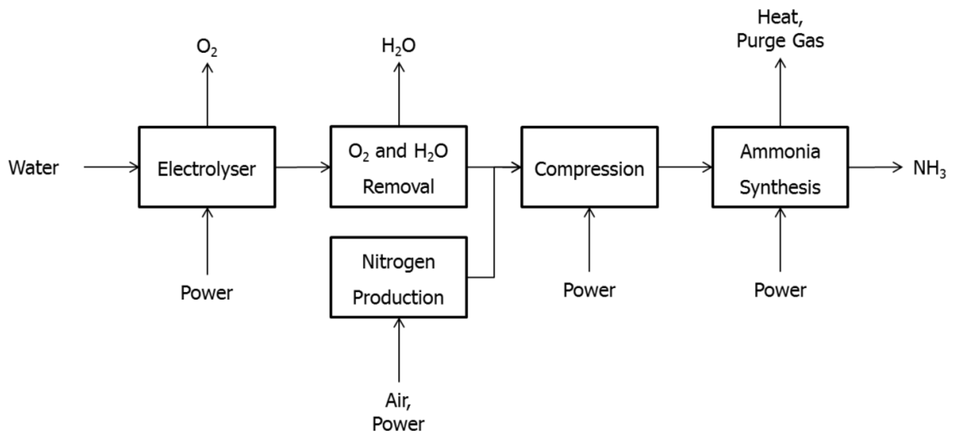
The Big Picture

- Ammonia has been recognised as a carbon free energy carrier
- Currently the most energy efficient Ammonia plant uses ~6.2Gcal per ton of NH_3
- Most of the energy input is in the production of H_2 from a hydrocarbon feedstock
- Alternative sources of H_2 generation will have a significant impact on the energy consumption and future competitiveness
- The capacity for "Green" Ammonia plant to be competitive is still under evaluation
- ✓ N_2 source will play a significant role – membrane or PSA rather than cryogenic

Economic Factors

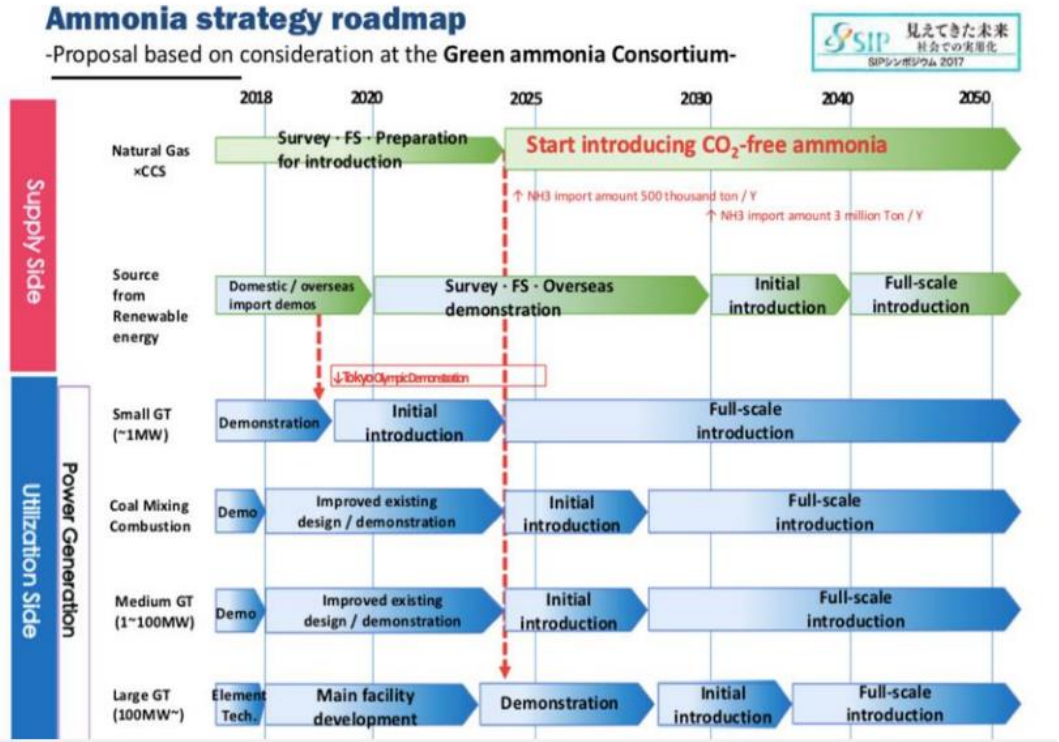
- Traditional natural gas-based ammonia production ranges from USD 200 / tNH_3 to USD 600 / tNH_3
- Currently, it is estimated that ammonia based on renewables costs USD 400 / tNH_3 to USD 700 / tNH_3
- However, costs will continue to fall in certain areas as renewable energy continues to drive costs down
- Financial institutions are favouring "green" projects over fossil fuel ones
- ✓ Better terms, lower interest rates





Ammonia Project Profiles

- **Yara / BASF** – Freeport – Traditional Haber-Bosch with KBR Technology Uses “isolated” pure hydrogen from over the fence as additional feedstock to traditional steam reformed methane.
- **Yara/Engie** - The two companies will test green hydrogen technology in fertiliser production and agreed to carry out a feasibility study together at the beginning of the March 2019. The study’s goal is to design a green hydrogen plant integrated with Yara’s existing ammonia plant in Pilbara, Western Australia. https://www.gasworld.com/engie-and-yara-to-test-technology/2016612.article
- **Siemens** – Oxfordshire – Green ammonia demonstration plant – demonstration of a pure green ammonia plant from wind powered electrolyser to ammonia synthesis and ammonia fuelled generator.
- **Hydrogen Utility (H2U)** – to go ahead with demonstration plant Australia.
- **Proton Ventures** – The Netherlands – Green ammonia demonstration plant planned for Jan 2020 based on Proton Ventures Battolyser technology.
- **JGC Corporation** – Fukushima, Japan – Green ammonia demonstration plant currently in operation using low temperature and low pressure technology.



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The Future: Green H_2 is fundamental to Enabling Carbon Utilisation

- **Push/Pull Factors**
  - ✓ CO2 credit/tax cost
  - ✓ Incentives for reinvestment in reuse of CO2
  - ✓ Regulation for minimum H2 content in domestic gas

- **Societal & Reputational Factors**
  - ✓ Consumer demand for greener products
  - ✓ Corporate demand for carbon neutral supply chains

PROOF OF CONCEPT

Oxalic Acid

LAB SCALE

Carbon Fiber, Acetic Acid, Ethylene Glycol, CO2 Fuel Cells, Fuel from algae, Graphene, DME

PILOT

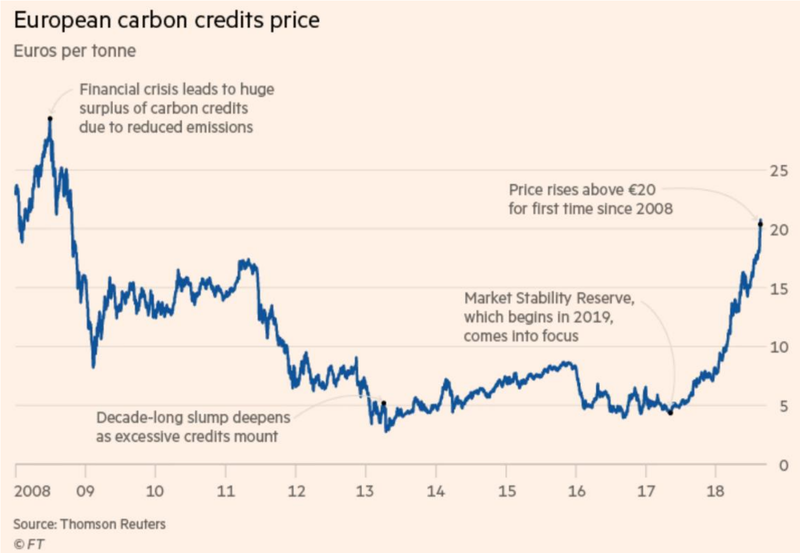
Formic Acid, Biochar, Bio-chemicals from algae, Power Cycles, Fuels, Food from algae

SEMI-COMMERCIAL

Formic Acid, Polymers

COMMERCIAL DEPLOYMENT

Urea, Sodium Hydroxide, Hydrochloric Acid, Cement, Sodium Carbonate, Aggregates, EOR, Methanol, Food Industry (incl. for green houses)

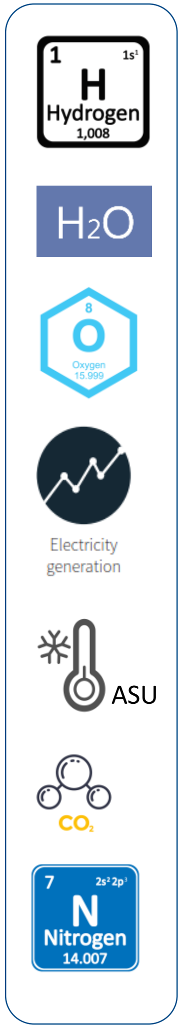


- **Research & Technology**
  - ✓ CC technology cost reductions – $20-84/ton achievable?
  - ✓ Fugitive emissions – methane gas approx. 3%
  - ✓ Falling costs of electrolysers
  - ✓ Development of turbines for mixed gas/H2

- **Markets**
  - ✓ Development of Asia trading markets for CO2
  - ✓ Revenue streams develop for CO2 receiving terminals

Proud history, bright future.

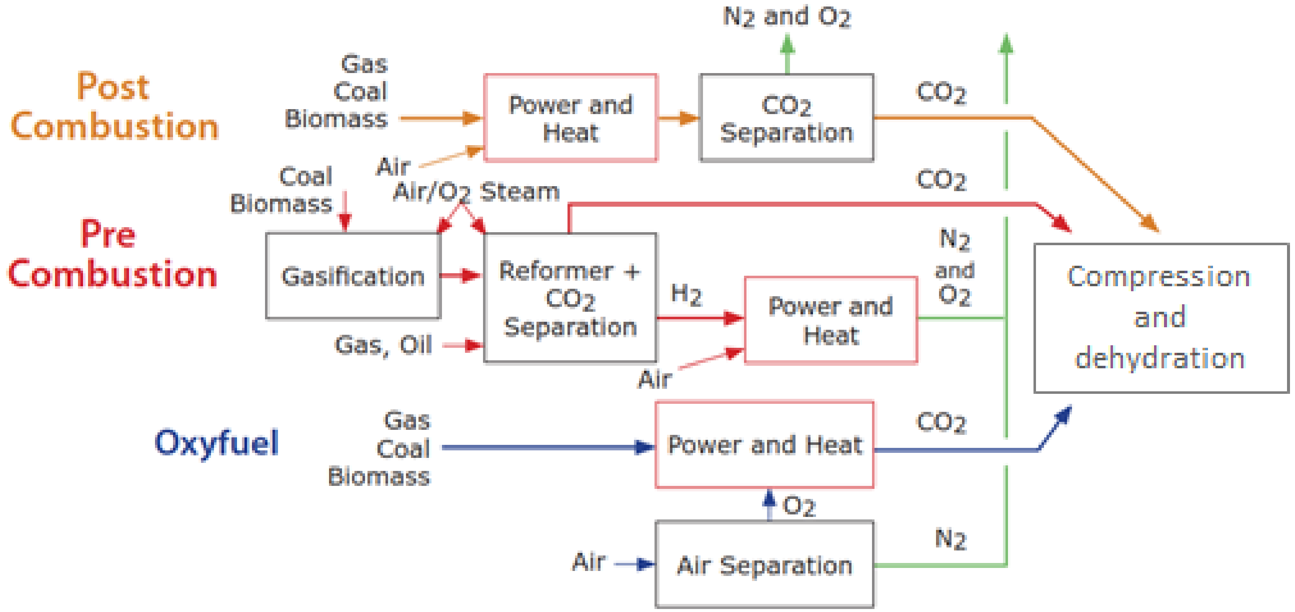
HydroChemicals – Vision of Production Potential



Sectors	Manufacture			
Agro Chemicals	Green Ammonia	Co2 Neutral UREA	Pesticides	Animal Feed - Protein
Methanol Value Chain	Olefins	Methanol to Ethylene Derivatives	FMCG – Household Products	EVA – Solar Panels
Ethanol Value Chain	Polymers	→ Gycol – Vinyl Chloride – Resins – Acetic Acids		
Mineral Crystallization	Lithium crystallisation	Battery production	Specialist Mineral Salts	
Carbon Fibre	Distressed Crude Oil →	Carbon neutral Specialist Carbon Fibre		
Construction	Mine Transportation Fuels	Green Cement Manufacture	Explosives	
Medical	Medical grade gases	Sodium Bicarbonate	Specialist antibiotics – Eg. Cefiderocol	

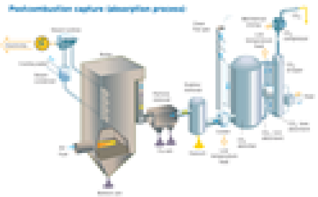
Increasing Client Operating Margin and Customer Demand

Carbon Capture



CO_2 Capture Technologies

Post Combustion

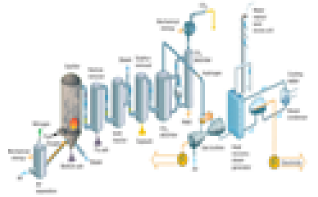


Concept:
- Capturing CO_2 from Flue Gases
- Operates at near atmospheric pressure

Advantages:
- Commercially proven
- Can be added to existing Power Generation facilities
- The upstream power plant is unaffected
- Cheaper than the other technologies

Disadvantages:
- Scale up ratio is smaller
- Reduces the overall energy efficiency (~ 15%). Although improvement can be achieved by heat integration with site
- Low partial pressures of CO_2 require special formulated solvents
- High oxygen content and other contaminants lead to high solvent degradation and increased make-up rates

Pre Combustion

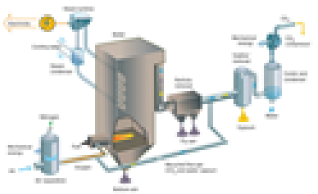


Concept:
- Converting Natural Gas to Synthesis Gas
- Capturing CO_2 at high pressure

Advantages:
- Well proven units of operation
- Large scale can be built;
- Centralised facility for multiple units possible
- Low energy for Carbon capture
- Operates at higher pressure

Disadvantages:
- It can be expensive due to ASU. Not attractive as an option for smaller units due to cost
- Energy expended in ASU and CO_2 capture

Oxyfuel



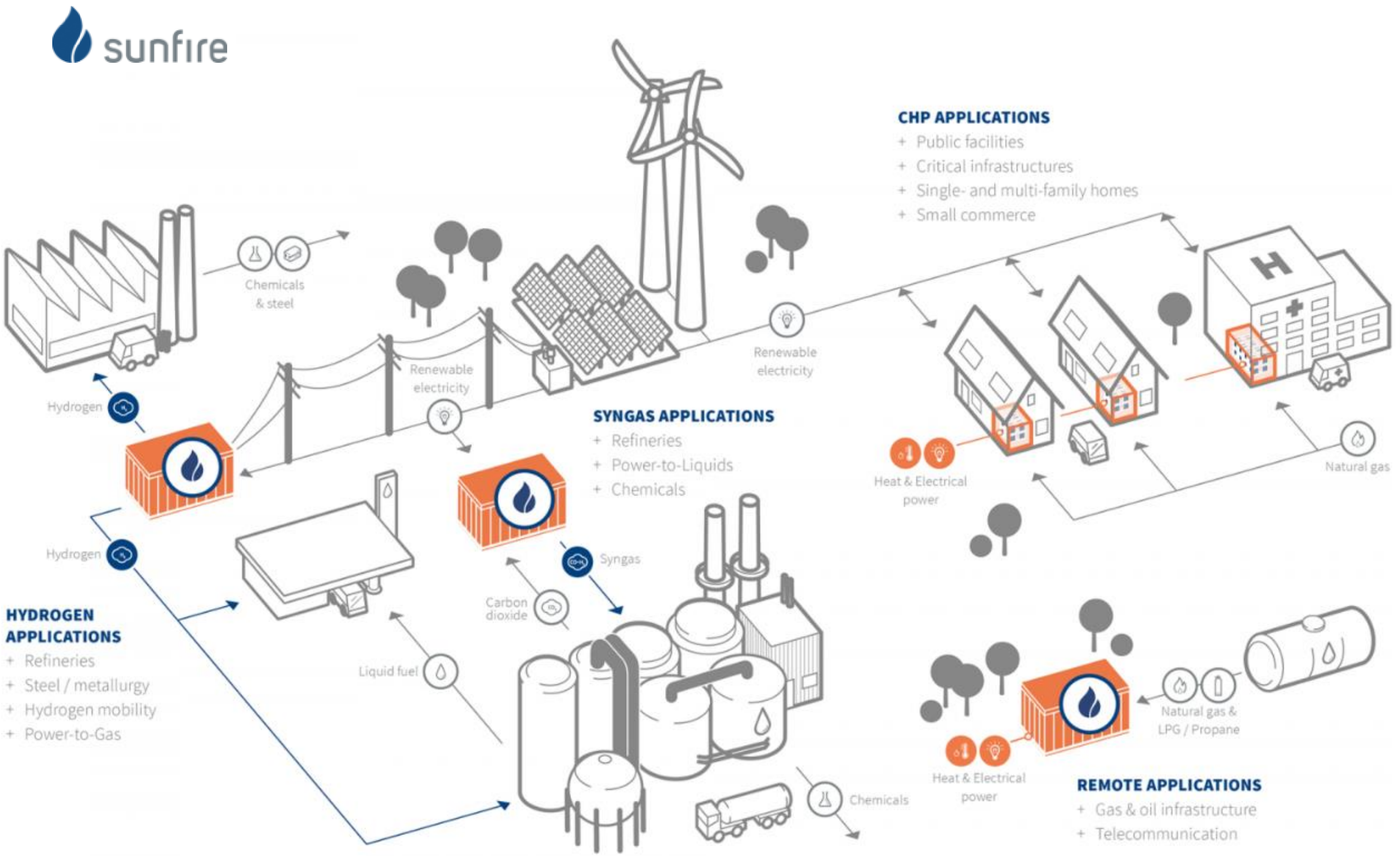
Concept:
- Burning Fuel in Oxygen instead of Air; Flue Gas is mostly CO_2 once the Water is removed

Advantages:
- May suit for new power generation units

Disadvantages:
- Not a good solution for retrofit
- Expensive due to ASU

Proud history, bright future.

CO_2 to Syngas



Pilot Plant Available

- Technology: Co-electrolyser based on solid oxide cell (SOC)
- ✓ Production of H2 and syngas
- Pilot plant in operation since 2015
- Engineering of Industrial scale started in 2017
- ✓ Expected operational in 2020

NEXT STEP: UPSCALING

- First commercial plant for the production of e-Crude planned in Norway in the industrial park of Heroya
- Electric input of 20 megawatts to produce 8,000 tons of e-Crude per year
- Utilizing cost-efficient renewable energy from hydropower
- Annual production volume sufficient to supply e.g. 13,000 cars with synthetic fuel avoiding 28,600 tons of CO_2 emissions p.a. from fossil fuels
- Partners: Nordic Blue Crude AS, Climeworks, EDL Anlagenbau and others

CO_2 to SYNGAS (cont'd)

Development Stage

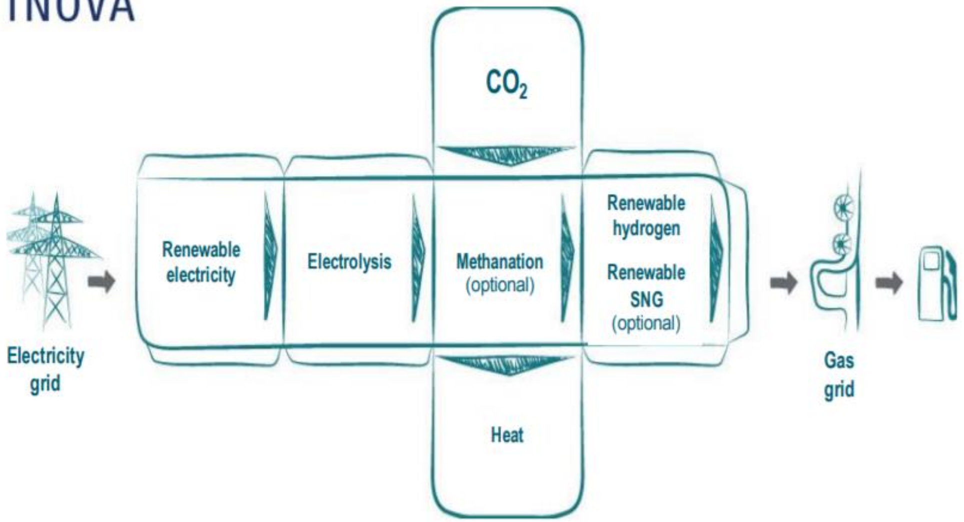
There are multiple institutions looking at transforming CO_2 into useful molecules via more efficient catalyst, membranes and electrochemical conversion

- MIT: converting power plant emissions of carbon dioxide into useful fuels via a membrane-based system
  - ✓ The membrane made of a compound of lanthanum, calcium, and iron oxide
  - ✓ Allows oxygen from a stream of carbon dioxide to migrate through to the other side, leaving CO
  - ✓ CO can be used to produced fuel, syngas, methanol, etc
- U.S. Energy Dept. Idaho National Laboratory: using switchable polarity solvents (SPS) that make the CO_2 more soluble and allow the carbon capture medium to be directly introduced into a cell for electrochemical conversion to syngas
  - ✓ Traditional approaches for reusing the carbon from CO_2 involve a reduction step that requires high temperatures and pressures
  - ✓ At lower temperatures, the CO_2 does not stay dissolved in water long enough to be useful
  - ✓ SPS shift polarity upon being exposed to a chemical agent. This property makes it possible to control what molecules will dissolve in the solvent
  - ✓ SPS-based process showed best results at 25C and 40psi
- University of Surrey: nickel-based catalyst to transform CO_2 into a synthesis gas and methanol

CO_2 to GAS (green CH4)

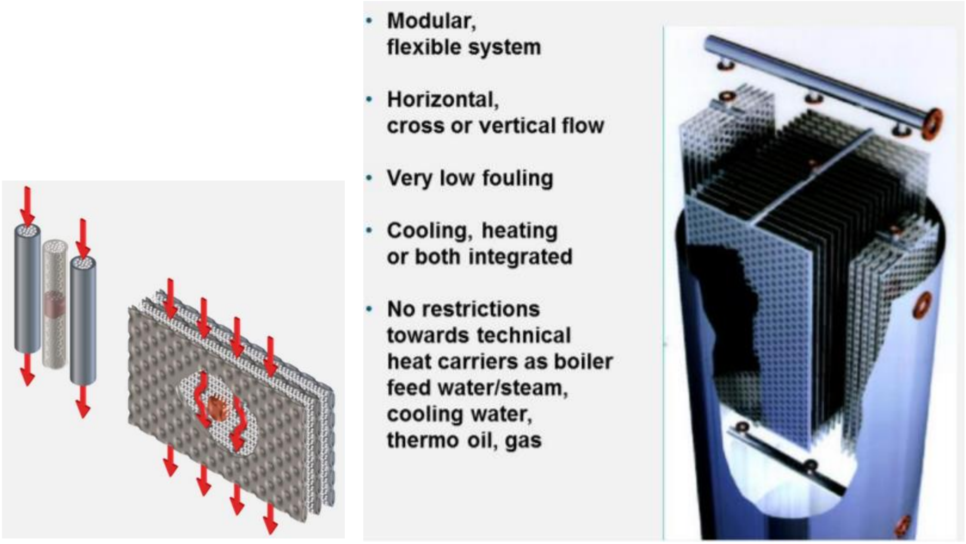
Hitachi Zosen INOVA

Pilot Plant Available



- Japan's first Power-to-Gas plant (PtG) of this kind, commissioning expected 2019-2020
- The objective of this test facility to prove the feasibility of large scale PtG plants
- Produced gas will be fed into an existing gas grid

- EtoGas catalytic reactor: Design of a plate methanation reformer fixed bed reactor system
- Proprietary electrolyzer with World's largest active area per cell (6,000cm^2)
- Power purchase mode: The e-gas plant follows the price for electricity dyamically, intermittently. Proven that their alkaline electrolyzer technology can follow dynamic loads



CO_2 to Chemicals (methanol/DME)

Commercially Available

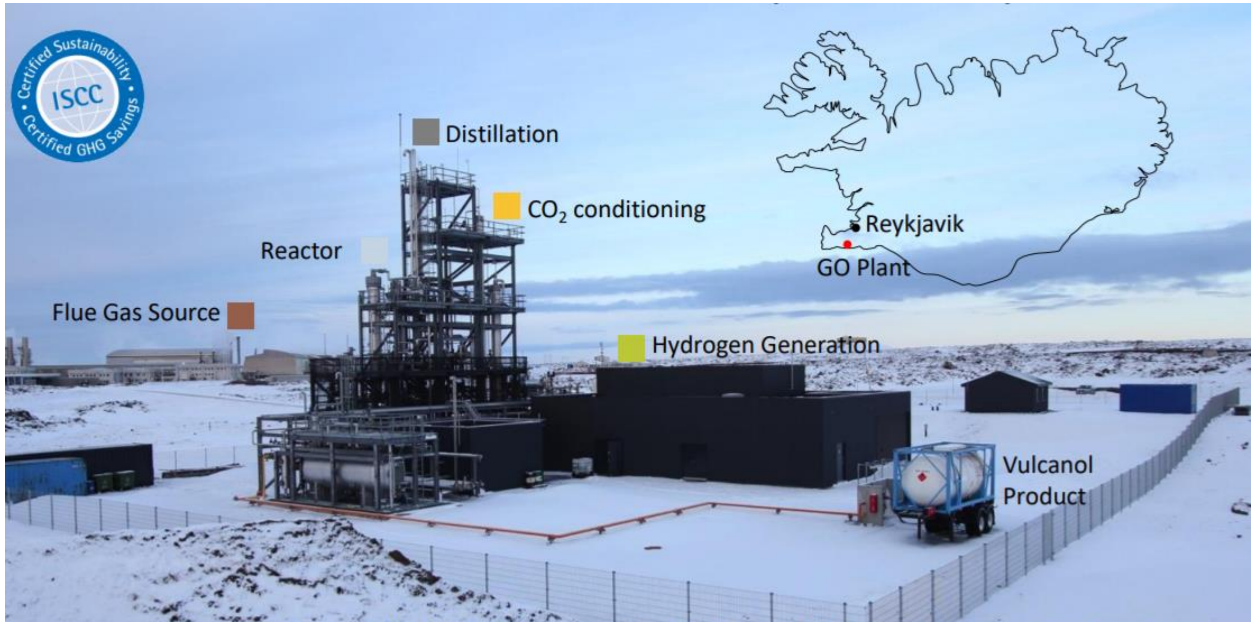
Methanol could be a sustainable source of fuel:

- Blends with gasoline
- Synthetic gasoline or fuels
- ✓ Dimethyl ether which can be used by diesel engines
- Marine fuel
- ✓ Minor modifications required on the supply infrastructure
- ✓ Engine modifications required
- ✓ Companies adopting duel fuel engines
- Waterfront Shipping Company Ltd., Mitsui O.S.K. Lines, Ltd., Marinvest/Skagerack Invest, and Westfal-Larsen Management

Future applications:

- Extension for electric vehicles, where methanol is used in a fuel cell to charge the vehicle while in operation
- ✓ Already under development

- DME production is still under evaluation



George Olah (GO) Renewable Methanol Plant, Svartsengi, Iceland
First commissioning: 2012
Capacity expansion: 2015
CCU throughput: 5,600 t/yr CO_2
Electrolyzer capacity: 800 t/yr H_2 (1200 Nm^3/hr)
Production capacity: 4,000 t/yr methanol

CO_2 to CONCRETE

Commercially Available

CO_2 Source

The CarbonCure Technology uses CO_2 sourced from industrial emitters. Established gas suppliers collect, purify and distribute the CO_2. The CO_2 is stored at concrete plants in pressurized vessels that are refilled regularly by the gas suppliers.

The Equipment

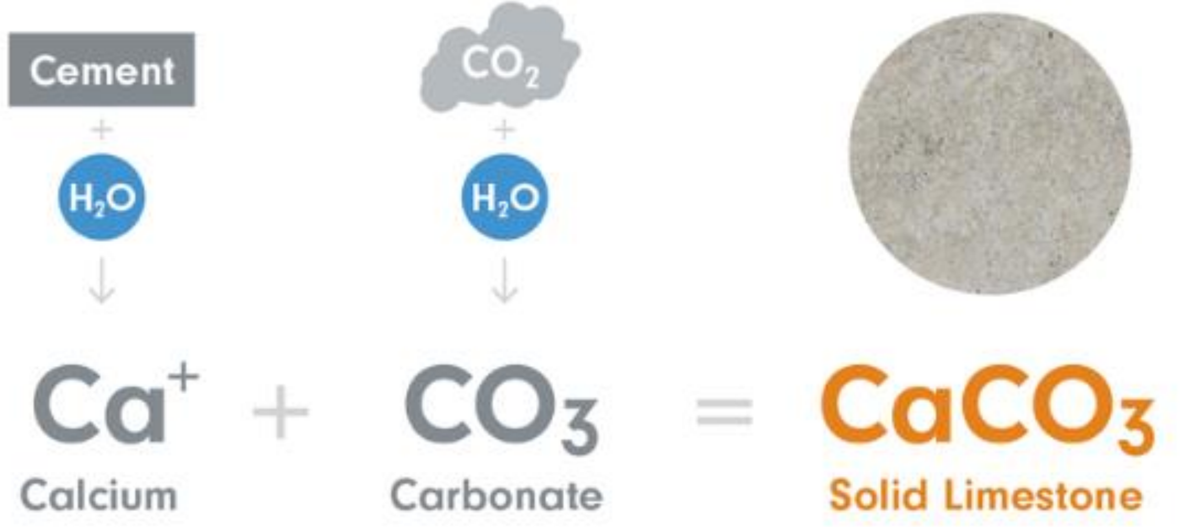
The patented CarbonCure Technology is retrofitted into existing concrete plants in a single day. Batching is controlled by a simple interface integrated with the batch computer. In a ready mix dry batch application, the CO_2 is injected into the hopper; while in a central mix or masonry application, the CO_2 is injected into the central mixer.

Effects on Concrete

The CarbonCure Technology has no effect on fresh properties, including set-time, slump, workability, pumpability, air content, temperature, and finishing; nor on hardened properties including pH, freeze-thaw, density, colour, texture, and durability.

Chemistry

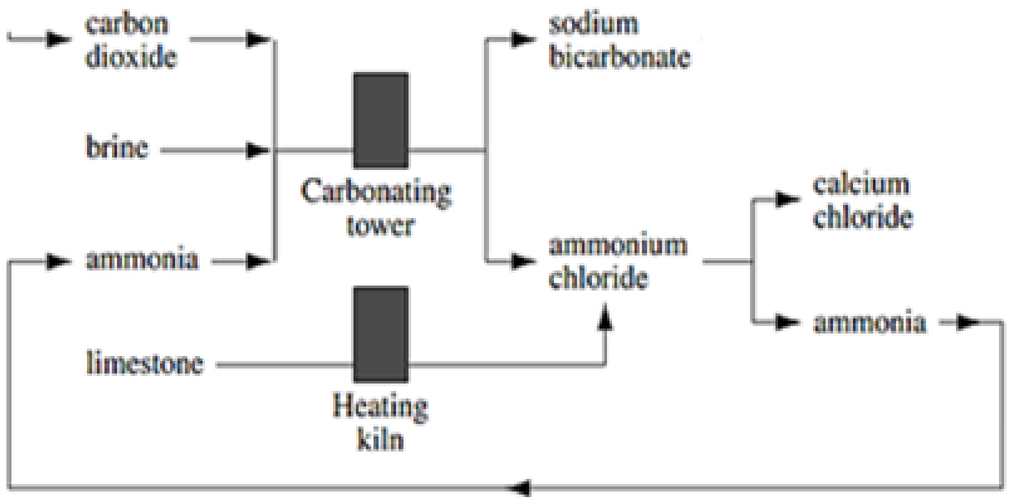
Once injected into the wet concrete mix, the CO_2 reacts with calcium ions from cement to form a nano-sized calcium carbonate mineral that becomes permanently embedded in the concrete.



CO_2 to Sodium bicarbonate

- Singapore's desalination industry creates around 100,000 m³ of brine every day
- Combined with pure CO2 from CCS this brine can be used to produce Sodium Bicarbonate

Development Stage



- Over the forecast period to 2021, world consumption is expected to continue to increase at a rate of about 2% per year
- The largest part of demand growth will be in Asian markets
- Sodium Bicarbonate Value USD 200 – 300 / tonne

CO_2 to Aggregates

Commercially Available

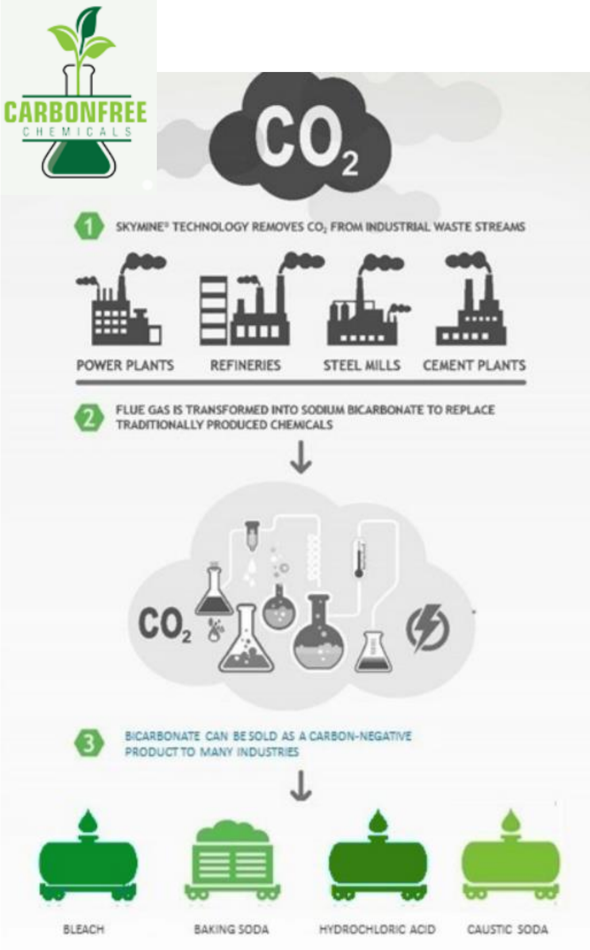
- Accelerated Carbonation Technology (ACT) – where waste carbon dioxide gas is used as a resource to treat a wide range of thermal wastes
- Technology accelerates the natural reaction, taking place in minutes, resulting in the formation of artificial limestone
- Significant volumes of carbon dioxide are permanently captured as stable carbonates
- The resulting aggregate has captured more carbon dioxide than is used in the energy required in its manufacture
- Applications: blocks, precast concrete, ready mix concrete, screed

The Carbon8 process has recently been recognised in a United Nations Environment Report and acknowledged as making “a demonstrable contribution to the developing European circular economy”

Commercial plants:

- Grundon Waste Management: two lines producing 30,000 (2012) and 65,000 (2014) tones of aggregate product per year
- A plant was commissioned in Avonmouth (2016)
- 2018 Engineering work carry out for Leeds plant 100,000 tonnes of lightweight manufactured aggregate

CO_2 to Inorganic Chemicals



Pilot Facility Available

CarbonFree Technology:

- Remove carbon dioxide (CO_2), acid gases such as sulfur oxides (SO_x) and nitrogen oxides (NO_x), and other heavy metals from industrial waste streams
- Commercially saleable products of hydrochloric acid, caustic soda, baking soda (sodium bicarbonate) and bleach
- Can be implemented for new industrial manufacturing plants, refineries, power plants, and steel mills, or can be retrofitted to current stationary emitting sources
- Can use waste heat or electricity to power its carbon-capture-and-utilization process

Demonstration facility:
Began operations March 2015 in San Antonio, Texas at Capitol Aggregates cement plant. The plant equipped with SkyMine®technology will reduce its carbon emissions by 15 percent – 83,000 tons of CO_2 annually

CO_2 to Protein

Development Stage

- Study by Lappeenranta University of Technology (LUT) and VTT Technical Research Centre of Finland have produced protein by using electricity and CO2
  - ✓ Protein produced in this way can be further developed for use as food and animal feed
  - ✓ The protein can be produced anywhere renewable energy, such as solar energy, is available
  - ✓ Currently, the production of one gram of protein takes around two weeks, using laboratory equipment that is about the size of a coffee cup
    - The next step the researchers are aiming for is to begin pilot production

Commercially Available

- Calysta FeedKind® uses microbes to turn natural gas – methane – into a high-protein food for animals
  - ✓ FeedKind® protein for aquaculture, livestock and pets
  - ✓ The process relies on microbes that feed on methane
  - ✓ CO2 and water are waste products of the process

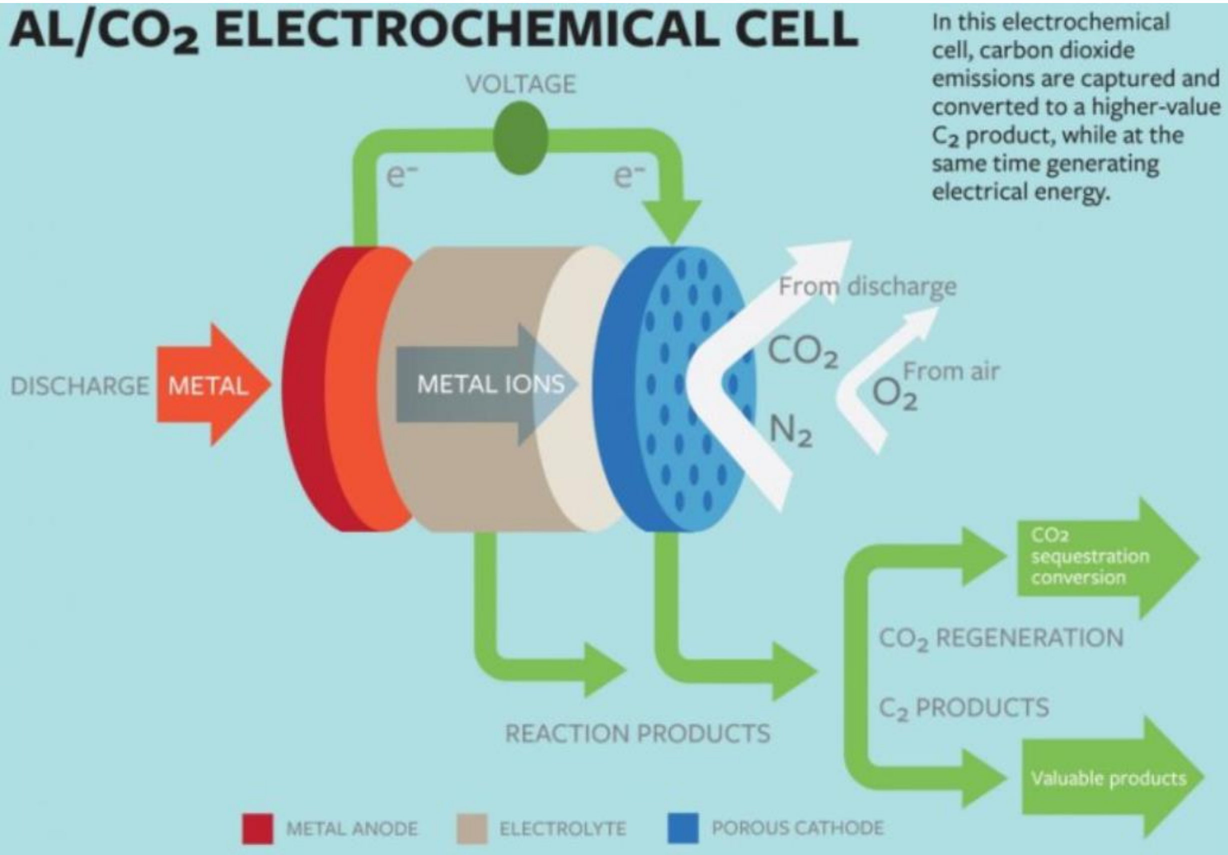
CALYSTA®

Superior High Protein Replacement for Fishmeal

	FeedKind® Protein	Fishmeal
% Protein	71%	60-72%
% Fat	10%	6-10%
% Fiber	<1%	<1%
% Ash	7%	10-15%
Shelf Life	>12 months	3-9 months

CO_2 FUEL CELL

Development Stage



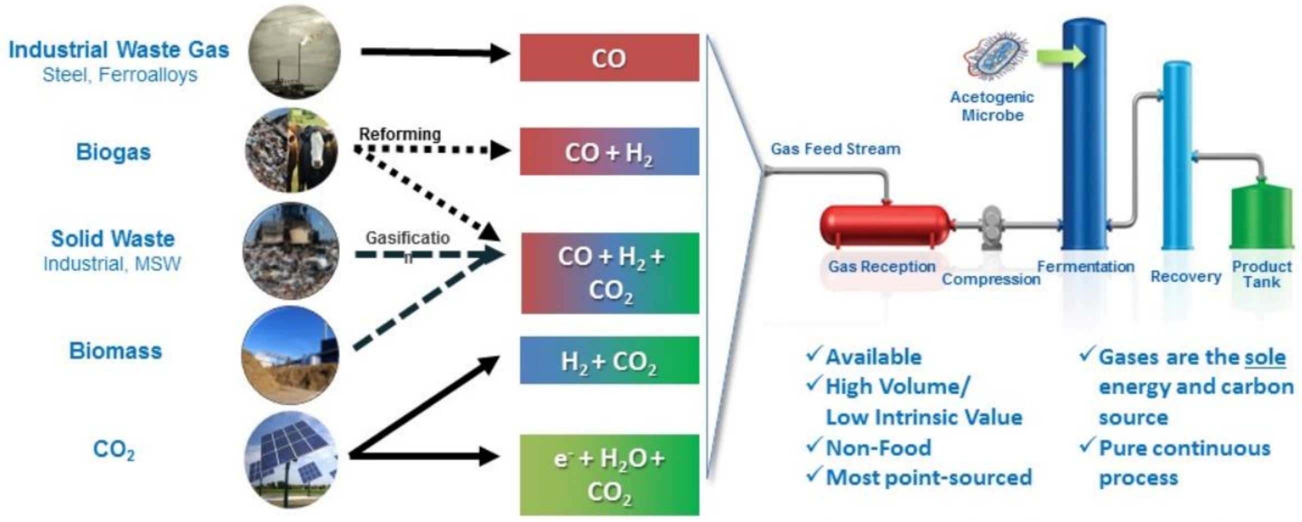
This graphic explains novel method for capturing the greenhouse gas and converting it to a useful product -- while producing electrical energy - *Credit: Cornell University*

- This electrochemical cell captures the greenhouse gas and converts it to a useful product while producing electrical energy
  - ✓ "Carbon capture" technologies -- chemically trapping carbon dioxide before it is released into the atmosphere
- How does it work?
  - ✓ Aluminum as the anode
  - ✓ Mixed streams of carbon dioxide and oxygen as the active ingredients of the cathode
  - ✓ The electrochemical reactions between the anode and the cathode would sequester the carbon dioxide into carbon-rich compounds
  - ✓ Also producing electricity and a oxalate as a byproduct
    - Carbon-carbon oxalate that is widely used in many industries, including pharmaceutical, fiber and metal smelting
- A current drawback of this technology is that the electrolyte - the liquid connecting the anode to the cathode - is extremely sensitive to water

CO_2 Bioconversion

LanzaTech capturing carbon. fueling growth.

Commercially Available



- Biological conversion of carbon to products through gas fermentation
- Using microbes that grow on gases (rather than sugars, as in traditional fermentation), carbon-rich waste gases and residues are transformed into useful liquid

- Proprietary microbes
- Exhaust directly taken from vents

- Commercial plant started operation in May 2018

KBR

CO_2 to Polycarbonates

Covestro Global Corporate Website

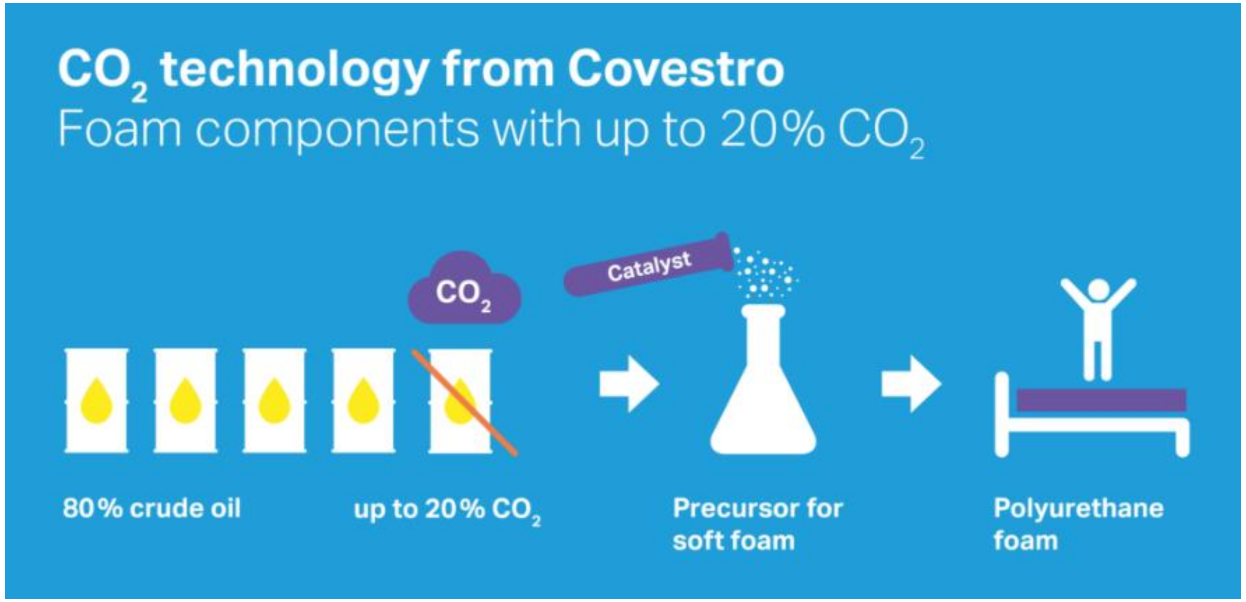
Science For A Better Life

Commercially Available

Cardyon® is an innovative raw material for the production of high quality, flexible polyurethane foams
It is made with carbon dioxide (up to 20%) – a raw material which is both abundant and available as a chemical feedstock

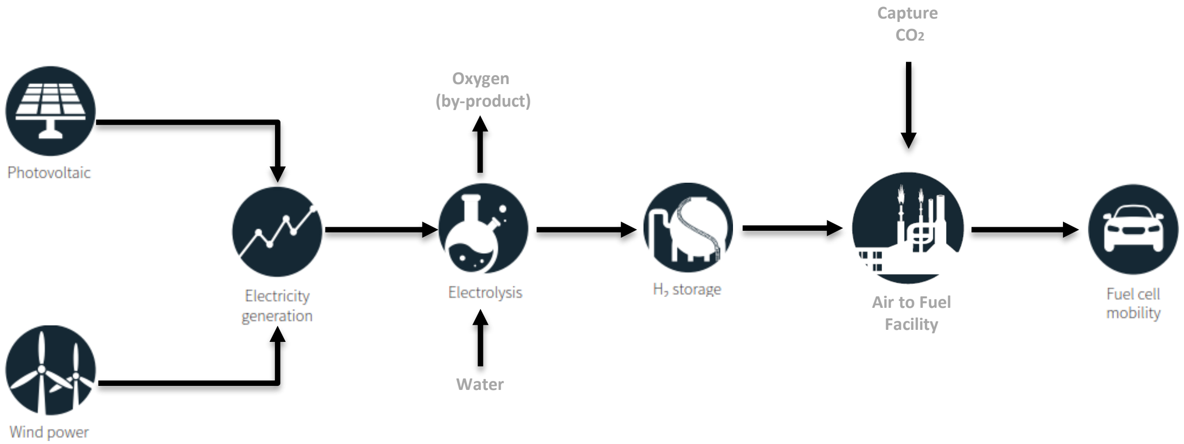
Since June 2016, Covestro has been operating its own production plant for the innovative polyols at its site in Dormagen, Germany. It has an annual capacity of 5,000 metric tons. The CO_2 processed is a waste product from a neighboring chemical facility

Covestro is working on developing a broad range of applications with CO_2-based polyurethane materials



Into the future: CC from Air

- Licensor: Carbon Engineering, CLIMEWORKS (Capturing CO_2 from air), Global Thermostat
- Separates CO2 from ambient air
- Potential end users:
  - **food and beverage industries**
  - **commercial agriculture**
  - **the energy sector**
  - **the automotive industry**



Agenda

Presentation

Decarbonisation Renewable Energy CO_2 Capture CCUS	45 minutes
K-SAAT	**15 minutes**
Plastic Recycling	20 minutes
QPinch	20 minutes
Energy Efficiency & Industry Trends	20 minutes

Proud history, bright future.

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Proud history, bright future.

Plastic Recycling

Strategy for Plastic in a Circular Economy

Plastic Recycling Models

Our Love of Plastic is on the increase

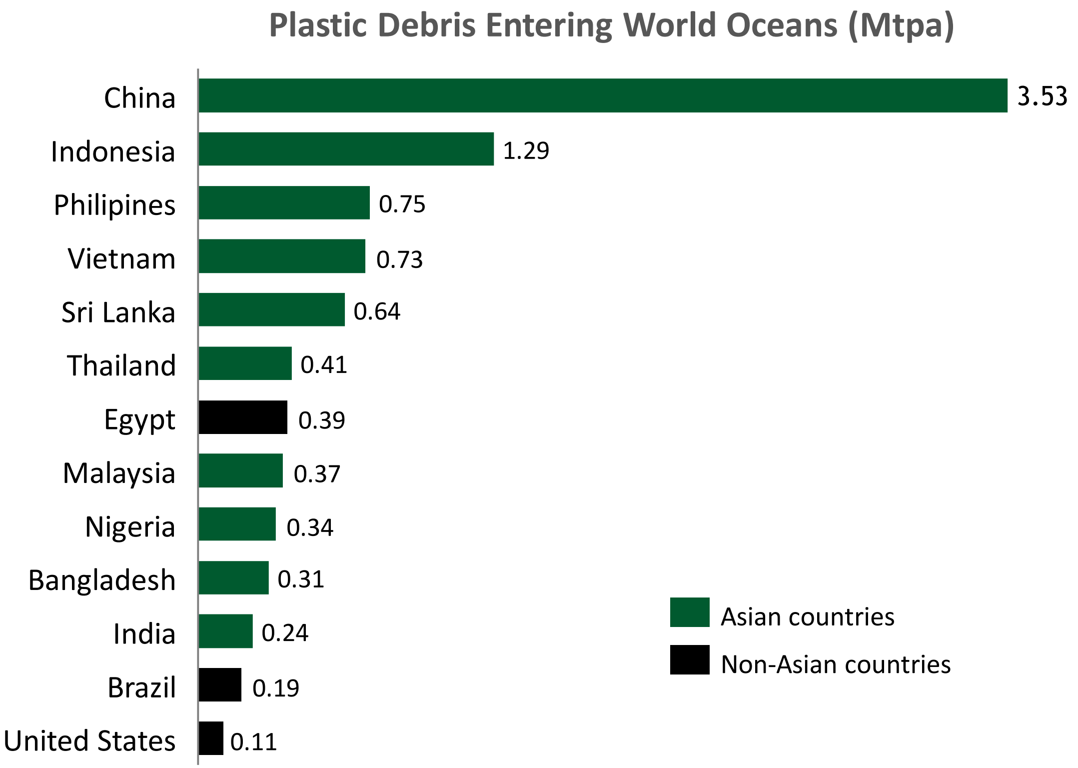
	2014	2050
Annual plastics production	311 MT	1,124 MT
Ratio of plastics to fish in the ocean (by weight)	1:5	>1:1
Plastics' share of global oil consumption	6%	20%
Plastics' share of carbon budget	1%	15%

Source: BCG & The Ellen MacArthur Foundation

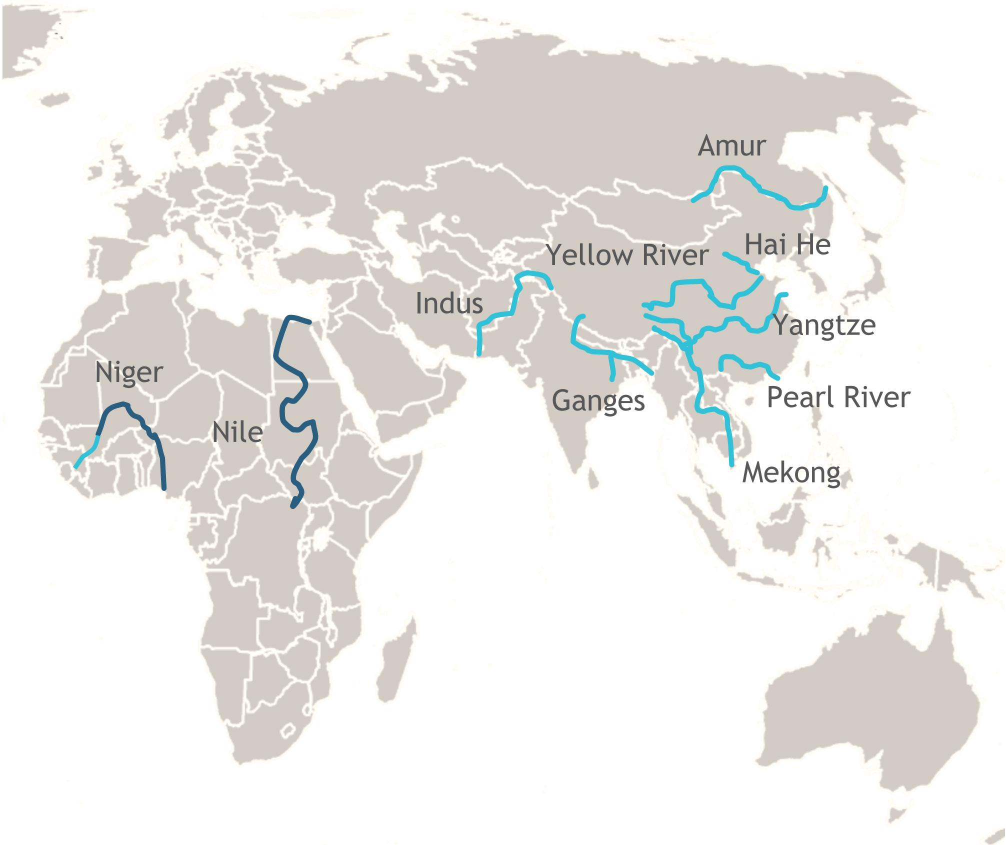
Proud history, bright future.

90% OF THE PLASTIC ENTERING THE SEAS COMES VIA TWO RIVERS

Developing nations without the necessary infrastructure



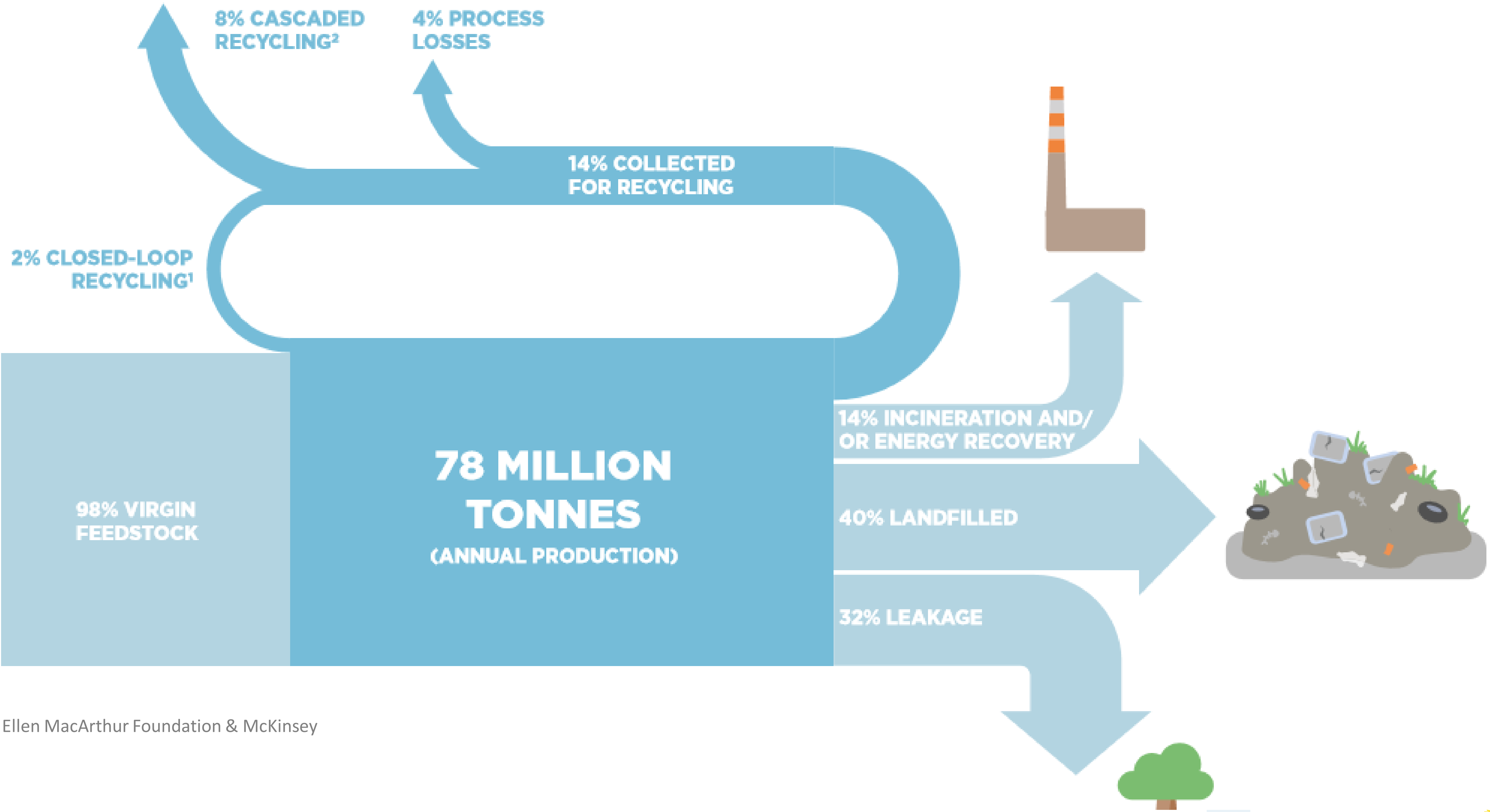
8 out of 10 most polluted rivers in the world are in Asia



Source: American Chemistry Council, Helmholtz Centre for Environmental Research, BCG

Proud history, bright future.

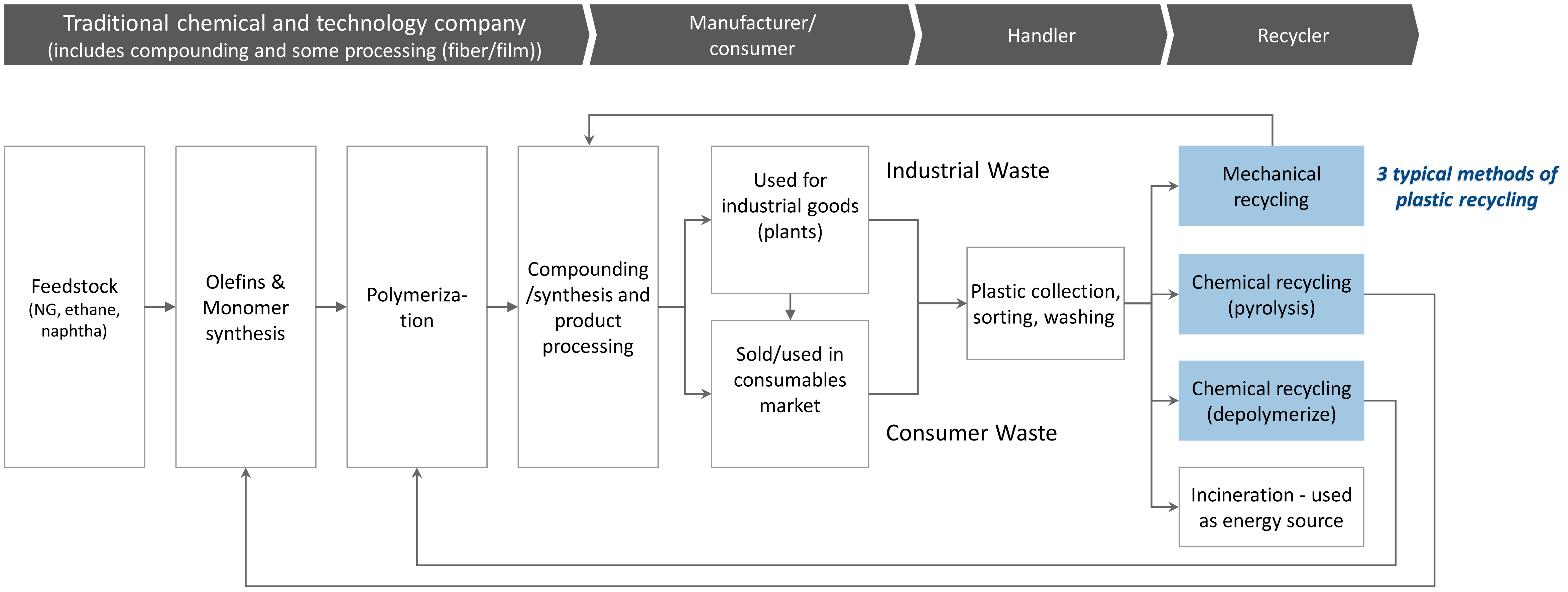
~10% Single Use Plastic gets back into the materials chain



Source: Ellen MacArthur Foundation & McKinsey

Proud history, bright future.

RECYCLERS WILL BEGIN TO TAKE PROMINENCE ON THE VALUE CHAIN



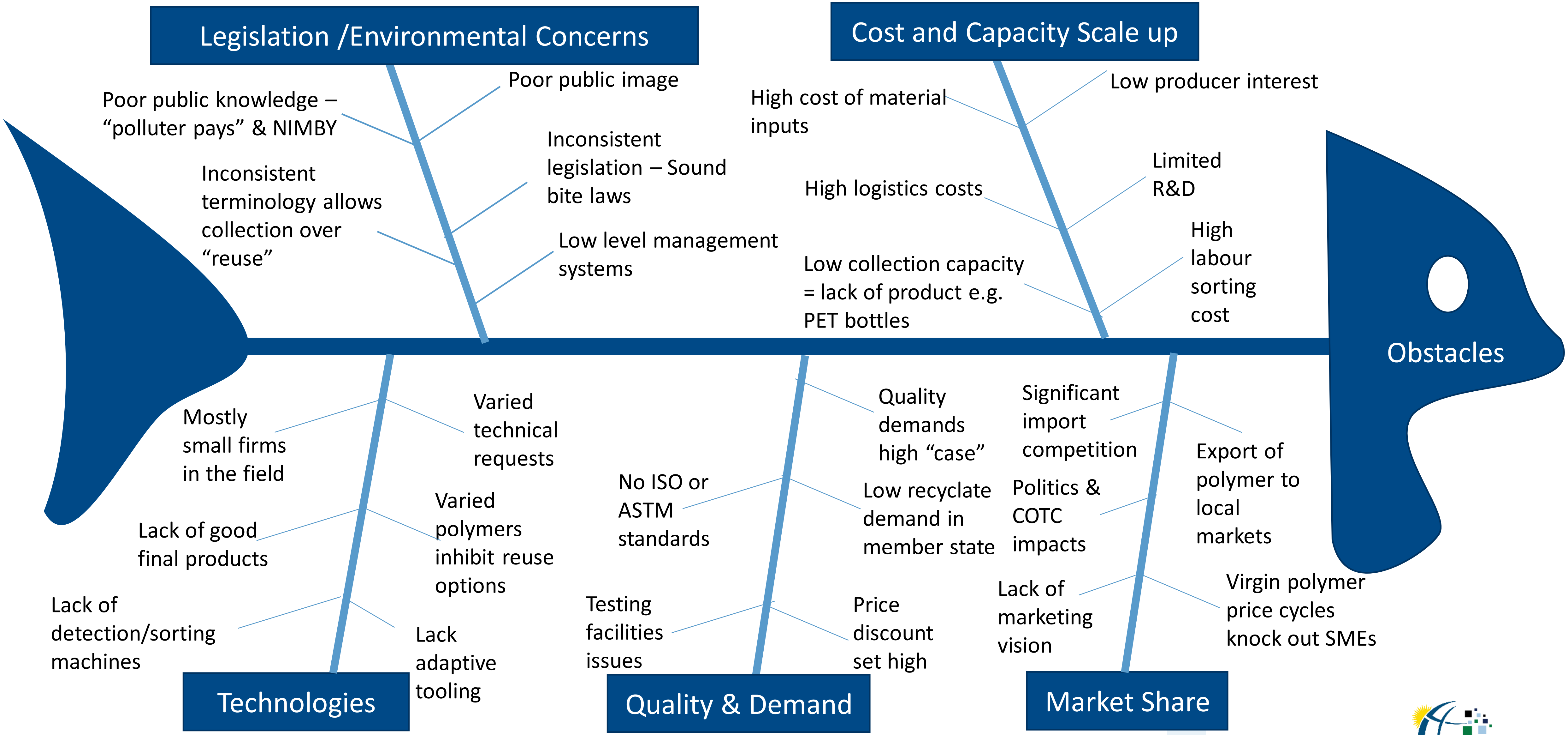
Source: BCG, KBR Consulting

RECYCLERS WILL HAVE WIDE RANGING IMPACTS ON PETROCHEMICALS

		Recycling process	Market maturity		Impact on petchem market	
Mechanical recycling		Separate through precipitation after removing contaminants through separation/ washing or dissolution	H	Typical recycling with highly mature biz model/technology • Difficult to gain economy of scale vs. petchem. Market fragmented by small/mid-size companies	M	Limited potential for technology innovation but likely to become a powerful competitor of virgin plastic under the circular economy
Chemical recycling	Depolymer ization	Depolymerize to monomers through chemical process and use as feedstock for polymerization	L	New area that requires development of economically feasible technology. Numerous start-ups are testing process	H	Significant part of the upstream plastic monomer market is likely to be replaced with scale expansion under economics gained through technology innovation
Chemical recycling	Pyrolysis	Produce petchem feedstock/fuel such as naphtha, paraffin by endothermic pyrolising of waste	M	Base technology was developed in 50's and commercialization began in 00's. However, business model/process improvement is required for full-fledged growth	H	Scale improvements through tech development. Options for Petchem producers to import greener syncrude

Source: BCG, KBR Consulting

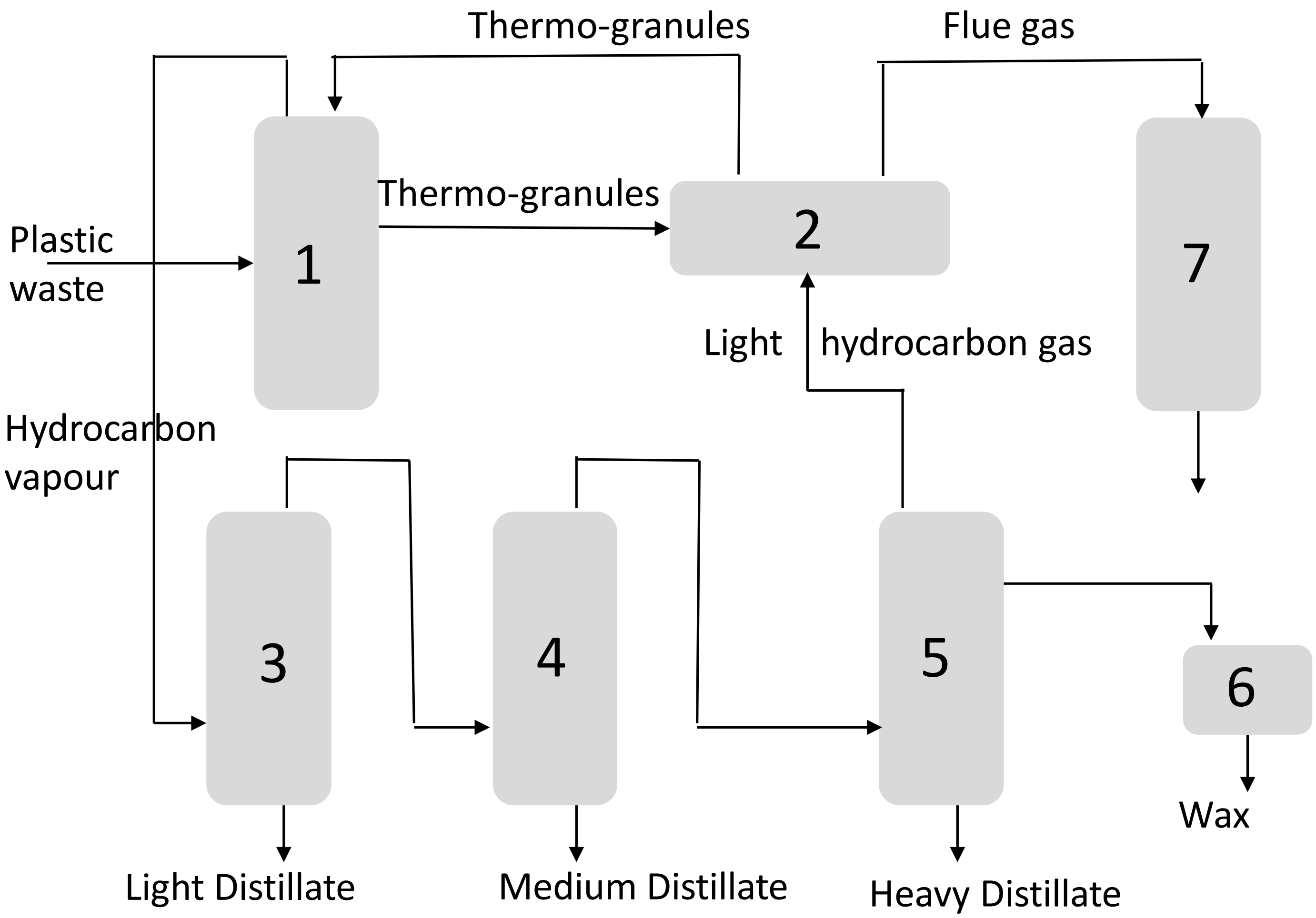
REPRESENTATION OF OBSTACLES TO PLASTIC RECYCLING



Proud history, bright future.

MIXED PLASTIC WASTE RECYCLE = CRACKER FEED

Plastic waste pyrolysis steam cracker feeds & waxes



1. Thermal Cracker
- Fluidised bed.
- Hydrocarbon vapour is refined of impurities.

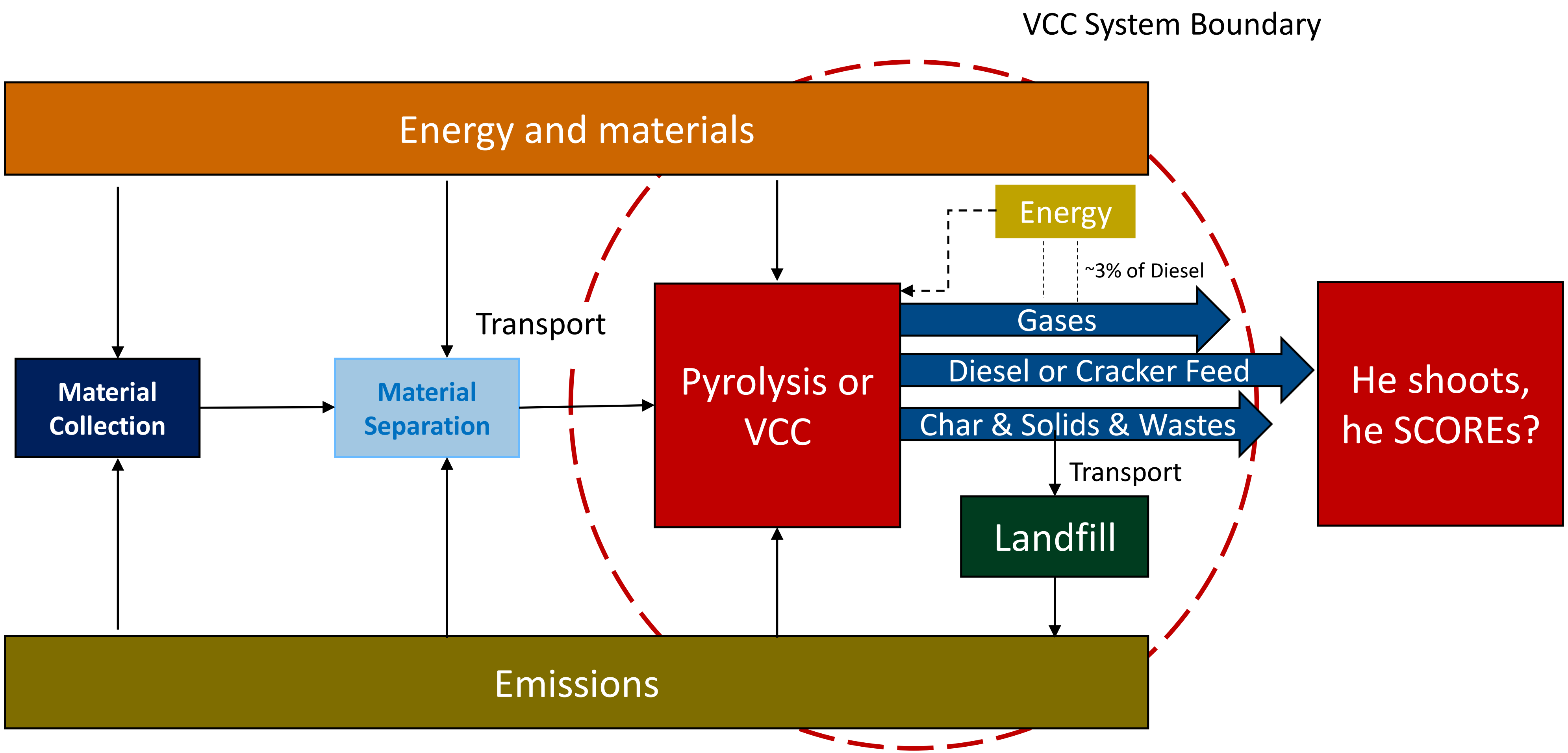
2. Regenerator
- Light hydrocarbon gas used as fuel to reheat thermo-granules from the cracker.

Units 3,4,5,6 Distillation
- Hydrocarbon vapour is condensed into Plaxx & stored.

7. Heat / Flue gas
- Remaining gas from the regenerator is treated.

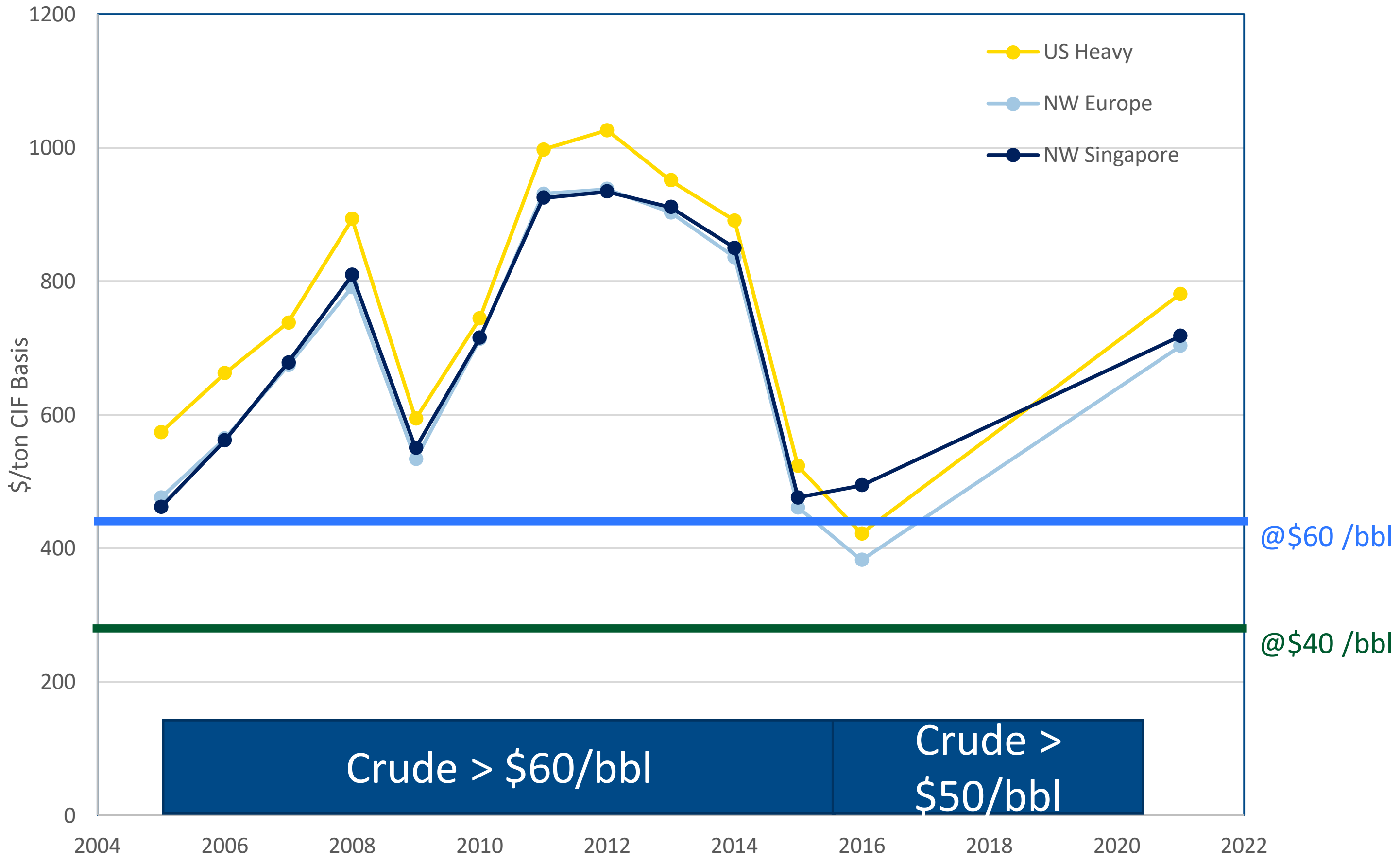
Performance Indicator	Value
Capacity (dry)	7000t plastic waste
Output	5,200t/year Product
Typical Yield	75%
Energy efficiency	85%
Lifetime	20 years

MIXED PLASTIC RECYCLE IS AN OPPORTUNITY FOR THE INDUSTRY & THE ENVIRONMENT

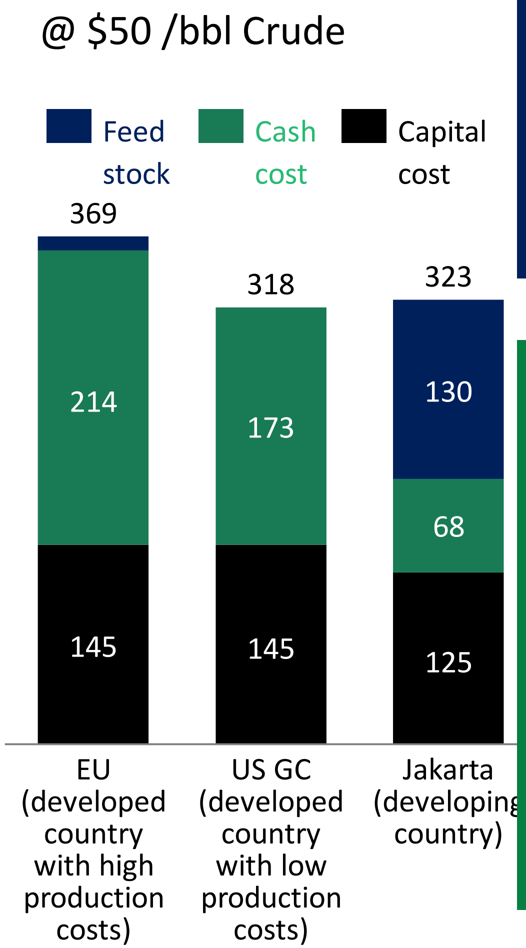


Proud history, bright future.

Syncrude has the potential to be a competitive Feedstock



SOURCE: IHS MARKIT & BCG ANALYSIS



FEEDSTOCK

- Feedstock (waste plastic) costs vary by region/supplier
- Influenced by distance from the processing plant share of imported waste plastic, etc. Can buy at a lower cost from countries with strict regulations (e.g. Singapore, US, etc.)

- Amortized costs and operating costs(utility/labor costs) vary by region/process type/process size/utilization
- Difficult to maintain scale and utilization rate due to the many variables in feedstock
- Need to maintain a certain distance from residential areas where feedstock can

SMALL SCALE RECYCLERS CAN SUPPORT LOCAL VALUE CHAINS

Multiple 8 TPA
The struggling Refiner / Petchem looking for life extension and sustainability options

Distributed pyrolysis and collection. Processed to plastics in smaller local facilities

The entrepreneurial waste company owner with an eye on the prize

Olefins & Monomer synthesis → Polymeriza-tion → Compounding /synthesis and product processing → Sold/used in consumables market → Plastic collection, sorting, washing → Chemical recycling (pyrolysis) → Olefins & Monomer synthesis

Sainsbury's

Returns to stores…….
Trash at service stations

New product innovations
"Local and sustainable packaging"

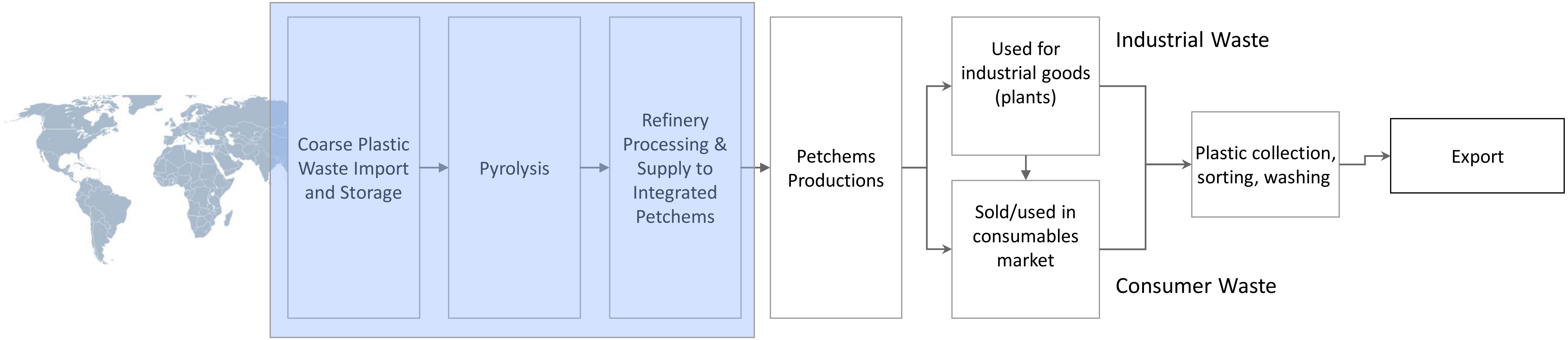
Demand stickiness
Local premiums
Government incentives

Smaller Scales
Higher fixed costs

Proud history, bright future.

PLASTIC WASTE BECOMES A COMMODITY FEEDSTOCK

50 KTA
VCC type facility upgrade to existing refinery
Import large volumes of plastic waste from global markets



Advantaged feedstock
Brownfield infrastructure
Scale

Lower value products

Proud history, bright future.

The world is moving from capitalism to sustainability

ALLIANCE TO END PLASTIC WASTE

DOW · SCG · Shell · BASF We create chemistry · TOTAL · NOVA Chemicals · Mitsui Chemicals · lyondellbasell · 台塑企業 · MITSUBISHI CHEMICAL · SUMITOMO CHEMICAL Co., Ltd. · ExxonMobil · Chevron Phillips Chemical Company LP · sasol · سابك sabic

The Alliance commits > $1.0 billion with the goal of investing $1.5 billion over the next five years to help end plastic waste in the environment

Tajikistan to abandon use of plastic bags

04 July 2018 - 18H13

Chilean court ratifies plastic bag ban after appeal

WorldViews

Mumbai's plastic ban carries costly fines and jail sentences for offenders

RECYCLING

IKEA U.K. and Ireland to Ban Single-use Plastic Straws

U.S. NEWS 07/16/2018 11:28 am ET | Updated 1 day ago

Adidas Pledges To Only Use Recycled Plastic By 2024

Polyester, which is made from plastic, currently makes up about 50 percent of the material in Adidas' products.

Why Starbucks, Seattle, and Tom Brady are all shunning plastic straws

BUSINESS • BRANDS

Marriott Will Stop Using Plastic Straws in all of its Hotels by 2019

Source: BCG,

Proud history, bright future.

KBR

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Heat transformer
Carbon Neutral Industrial Energy from Waste Heat

QPINCH

Low Grade Heat Recovery

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Plastic Recycling	20 minutes
QPinch	20 minutes
Energy Efficiency & Industry Trends	**20 minutes**

Proud history, bright future.

Energy Efficiency & Industry Trends

What are Global Competitors Doing?

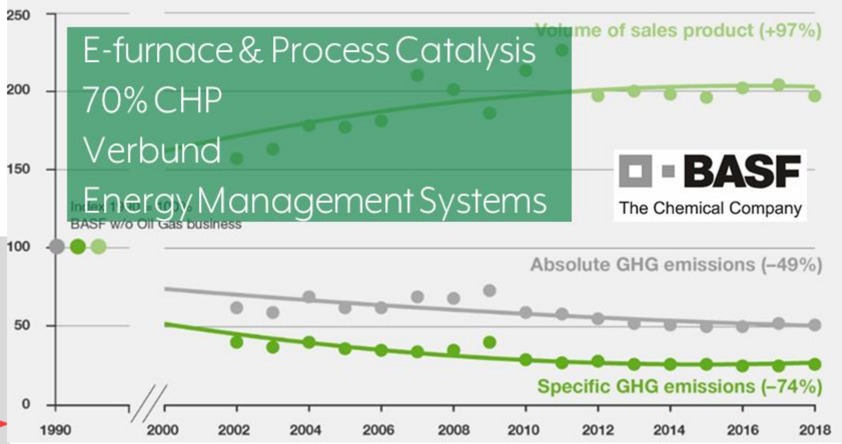
Remote Monitoring

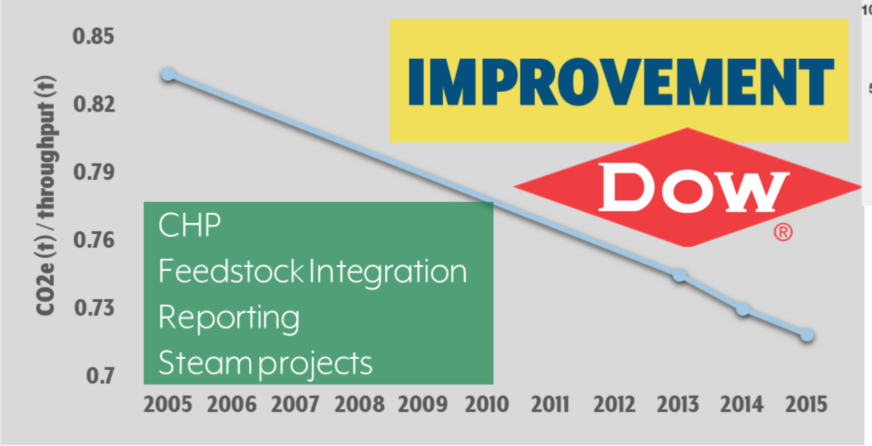
Distillation Column Optimisation

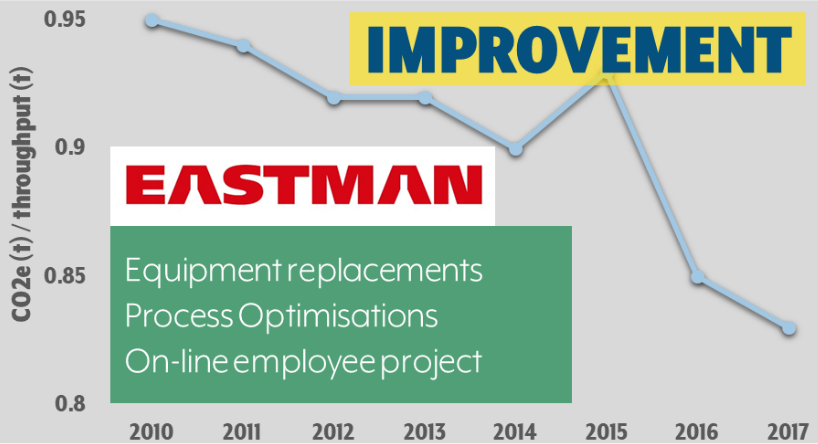
Low Grade Heat Recovery

QPinch

The process industry is responding to energy efficiency and sustainability pressures







IOCS

Big ticket items, complementary to upstream activities:

- AI
- Renewables & CoGen
- CCS

Petchems

A blend of large CAPEX & Strategic

- CoGen
- Waste to Power
- Woodchip switch
- CC

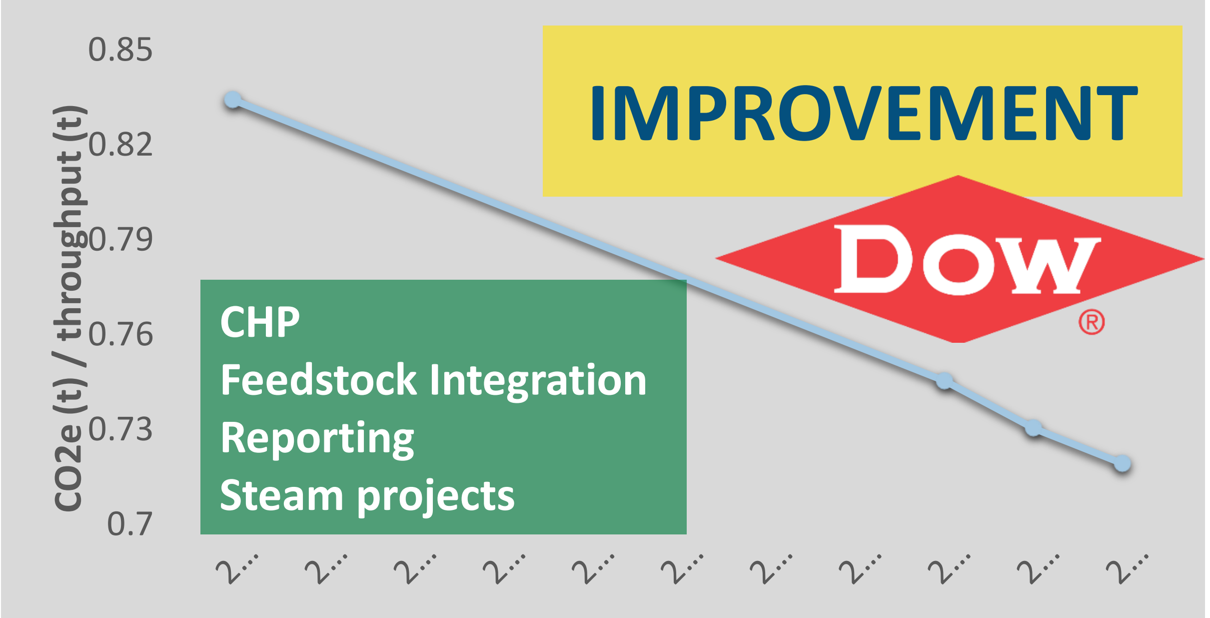
Innovators

New ideas and opportunities:

- Qpinch
- CO2 Ringmain
- Plastics Recycling
- Biofeedstocks

DOW Analysis

DOW GHG CO_2 intensity



External (Industry and Government) Engagement

- **U.S. Department of Energy (DOE) Energy assessed a Dow site using DOE's Steam System Assessment Tool (SSAT).**
- **Approximately $2 million in savings was achieved from steam trap and leak repair campaign, increase of condensate recovery and blowdown heat recovery.**

Strengths

Combined Heat and Power

85% of Dow's electricity in the United States and 70% worldwide is now produced through cogeneration.

Feedstock Integration

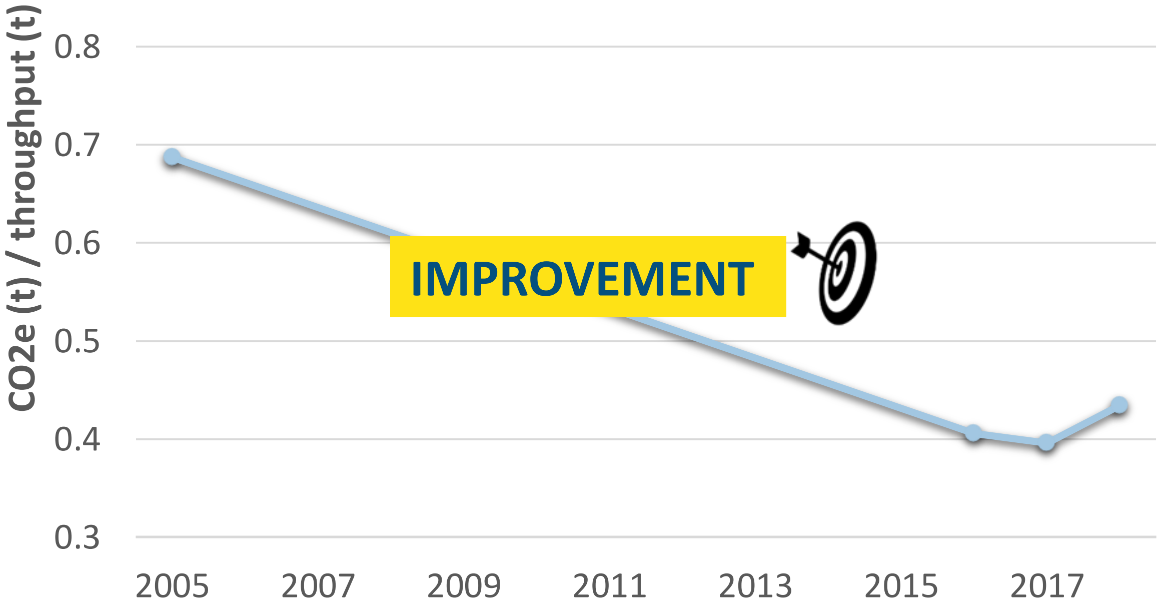
Case study – Propylene is used by the performance materials division in the production of propylene oxide, epoxy, and plastics additives. Dow have integrated propane dehydrogenation plants (savings in feedstock cost, transportation and from energy integration).

Reporting

- All sites and plants report energy intensity. Anyone within Dow can access this data viewing progression trends, for a single plant, a whole site or the entire corporation.
- Businesses use this to benchmark their plants, estimate potential energy savings and develop long-range improvement plans.

Covestro Analysis

Covestro GHG CO_2 intensity



Recent Activities

- Covestro has launched a plant in Dormagen near Cologne in Germany that uses carbon dioxide as a raw material in the production of plastics.
- The company is, for the first time, using carbon dioxide instead of crude oil on an industrial scale, creating a foam component made with 20% CO_2.

Covestro flagship solutions

- Renewable hardeners
- Gas phase technology
- CO2 technology
- Oxygen depolarized cathodes
- Bio-based aniline

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BASF Analysis

Energy Management

- Certified EMS (based on ISO50001) at sites to cover 90% of primary energy demand.

Process Integration

- BASF has six Verbund sites. Verbund - supply chain where the byproducts of one operation get converted into starting materials of another operation.
- 50% of Verbund savings wastewater, steam and electricity cost savings.
- Annual savings of more than €1 billion through Verbund. In 2016 BASF saved around 19 million megawatts per year. That reduces CO_2 emissions by 3.8 million metric tons annually.

Technology Development

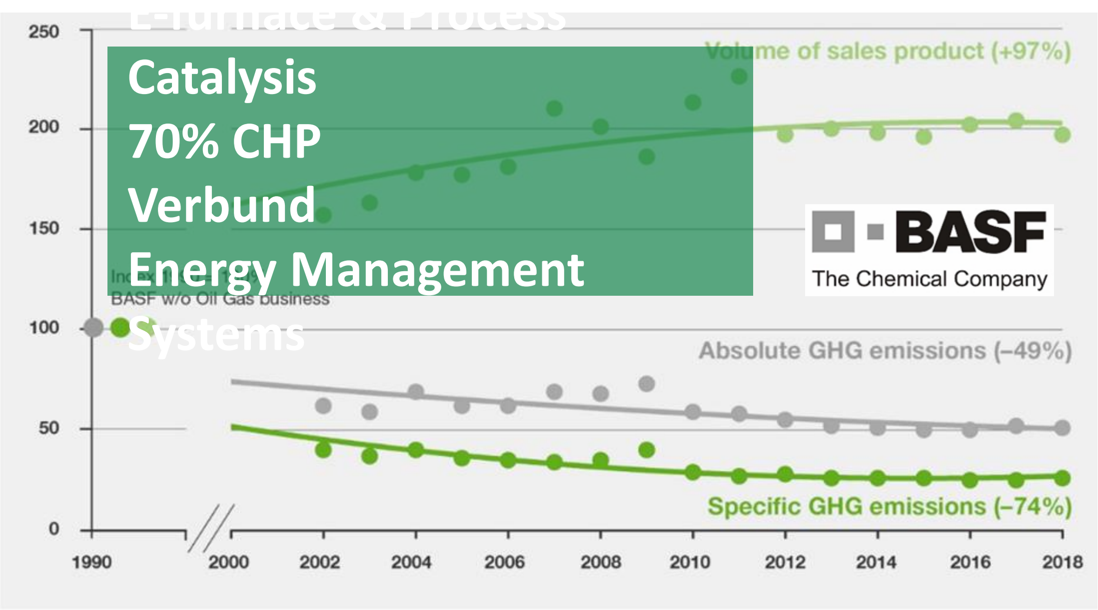
- BASF are developing an electric furnace to replace gas-fired furnaces in steam crackers.
- E-furnace run on renewable energy could reduce emissions by up to 90%.
- CO2 as feedstock for sodium acrylate. This reduces 30% of the fossil fuel feedstock.

Combined Heat and Power

- BASF were able to meet around 70% of their electricity demand and saved about 12.7 million MWh of fossil fuels in 2017.
- Corresponds to 2.6 million tons worth of prevented carbon emissions.

High Performance Catalysts

- BASF is developing low-emission processes especially in the production of high-volume intermediate olefins using new, high-performance catalyst systems.
- These catalysts are being marketed in cooperation with Linde.

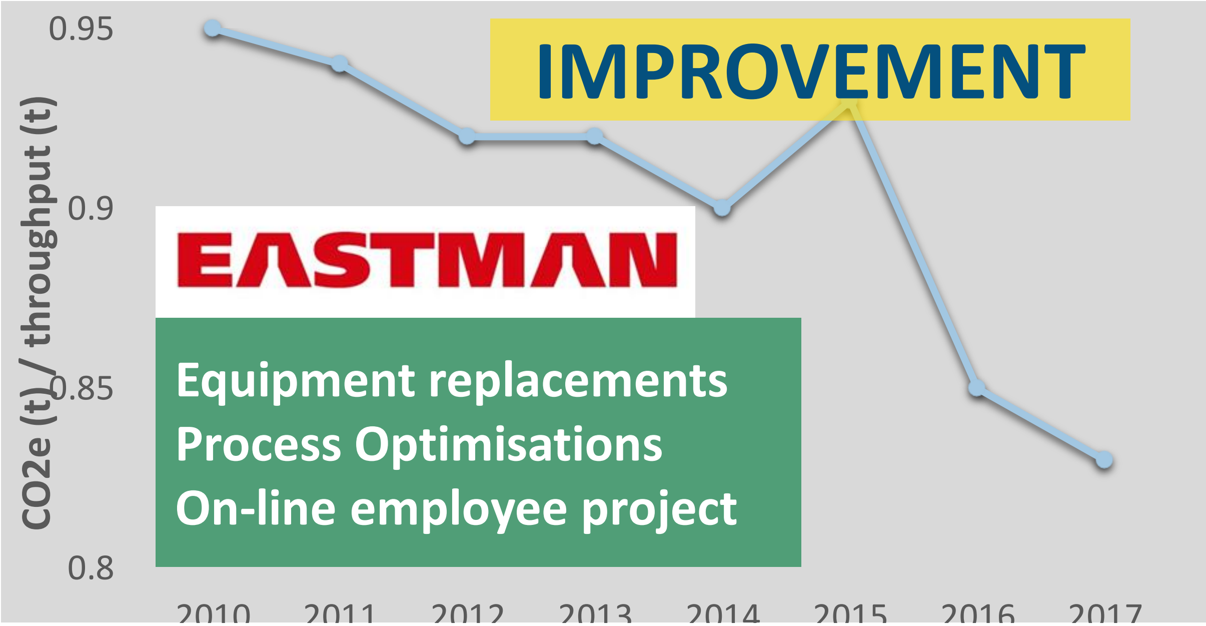


Volume of sales products and greenhouse gas emissions 1990 - 2018

Since 1990, BASF has reduced its CO_2 emissions by 50% despite doubling its product output.

Eastman Chemical Company Analysis

Eastman GHG CO_2 intensity



EASTMAN

Improve efficiency

Optimisation focussed

Recent Process Optimisation Approaches

- Running a line from a source of high pressure natural gas to eliminate a compressor used on low pressure natural gas
- Replacement of old equipment with newer more efficient equipment (i.e. boilers, pumps)
- Installing additional piping to allow condensate return
- Fine tuning temperatures of heat exchangers using refrigeration and steam to meet but not exceed requirements
- Installing variable frequency drives to eliminate control valves.
- On-line energy project saving calculator to encourage employee engagement identifying energy saving projects. Systems are in place to maintain savings.

Other Companies

Shell

Smart downstream solutions is using AI solutions to:

- **Predict consumer demand for petroleum**
- **Measure supply shortages, if any**
- **Recommend a correct mix of oil for a refining process.**

Renewable Energy

- Continued investments in wind, *solar* and biofuel industries.
- The Moerdijk chemicals site in the Netherlands has installed a solar power plant with a peak capacity of around 27 megawatts from 76,000 solar panels.

Carbon Capture and Storage

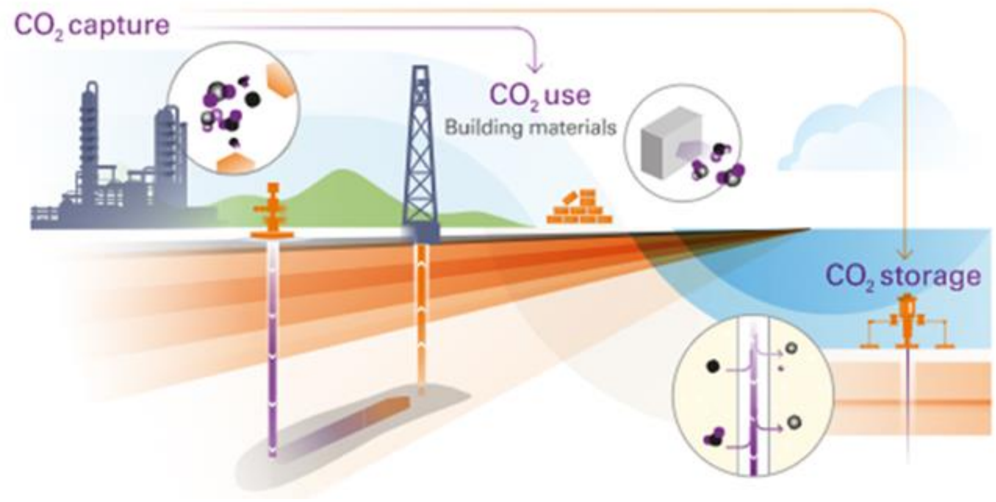
- **The Quest carbon capture and storage facility has captured and safely stored 4 million tonnes of CO2, ahead of schedule and at a lower cost than anticipated.**

BP

Waste Heat Recovery:
Example is installation of equipment to generate steam from exhaust gas at their Whiting refinery in the US which in turn reduces fuel gas requirements for their boilers and subsequently a reduction in GHGs.

Combined Heat and Power

- BP continue to invest in cogeneration for their plants.



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Other Companies (cont'd)

INEOS

Combined Heat and Power
Recent acquisitions and co-investment in CHP plants in Belgium and Scotland.

INEOS will invest £350 million at Grangemouth in a new energy plant. Replacing one of its two power stations with a new state of the art steam and power plant.

INEOS
THE WORD FOR CHEMICALS

Feedstock Integration

Contract signed to construct a world-scale propane dehydrogenation unit and a gas cracker (feedstock and energy integration).

Waste to power plant in Runcorn

DuPont

Major investment by DuPont in making its Grindsted plant carbon-neutral by switching from coal to wood chips and increasing the supply of surplus heat to the local district heating.

Plant reduces CO_2 emissions by 64,000 tonnes.

DUPONT

Combined Heat and Power

- Dupont continue to invest in cogeneration for their plants.

Mitsubishi Heavy Industries

Completed installation of a CO_2 capture unit at Nippon Ekitan Corporation's Mizushima Plant. Unit offers a recovery capacity of 283 metric tons per day.

Captured CO_2 is fed to Nippon Ekitan's new liquefied carbonic acid gas production facility.

MITSUBISHI
HEAVY INDUSTRIES

KBR

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Other Companies (cont'd)

BOREALIS Group

Energy management system in place compliant with ISO50001 for 8 sites.

Regular energy audits and review of projects RoadMap.

Low Grade Heat Upgrade Project

Using innovative technologies (QPinch) to improve energy performance by recovering low grade heat (expected in operation end 2019)

RELIANCE

Cracker convection coil internal cleaning by pigging method.

Flare Tip Replacement by High energy efficient flare tip – reducing steam and fuel gas requirement for combustion of flared gases.

Heat integration projects and steam trap programme.

SABIC

Established SABIC Certified Energy Expert Program aiming at improving in-house energy efficiency capabilities.

22 of these mega-projects, and we identified 9 million gigajoules (GJ) of potential energy-efficiency-improvement opportunities.

MTBE plant heater coils cleaning programme reduced the site's emissions by 4,300 metric tons of CO_2 each year.

Energy dashboards in Cartagena facility (improved energy intensity by 0.9%).

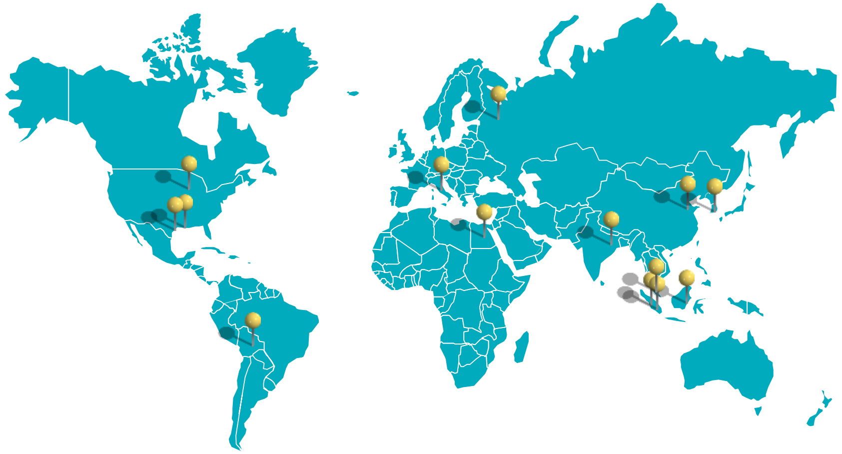
CO_2 from ethylene glycol plant is purified and utilize (urea, liquefied CO_2 for food and drink industry, methanol)

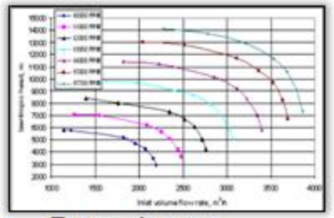
Remote Monitoring Applications

Monitoring Applications

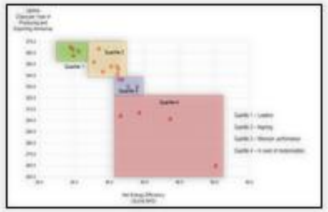
KBR InSite® delivers continuous operational and economic benefits through monitoring and analysis of plant operation using key performance indicators to field mobile devices.

Global Implementation – currently in operation in 14 sites. globally





- Data sheets
- Technical manuals
- Operating procedures

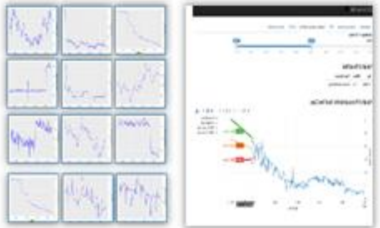


- Benchmark
- Best practices
- Lessons learned
- Proactive engagement

- KPI trends
- Smart alerts

- KPI evaluation
- Asset performance
- Production accounting
- Energy and emission reporting

- Data validation
- Anomaly detection
- Proprietary algorithms
- Heat and material balance



- Optimization
- Root cause analysis
- Operations diagnostics

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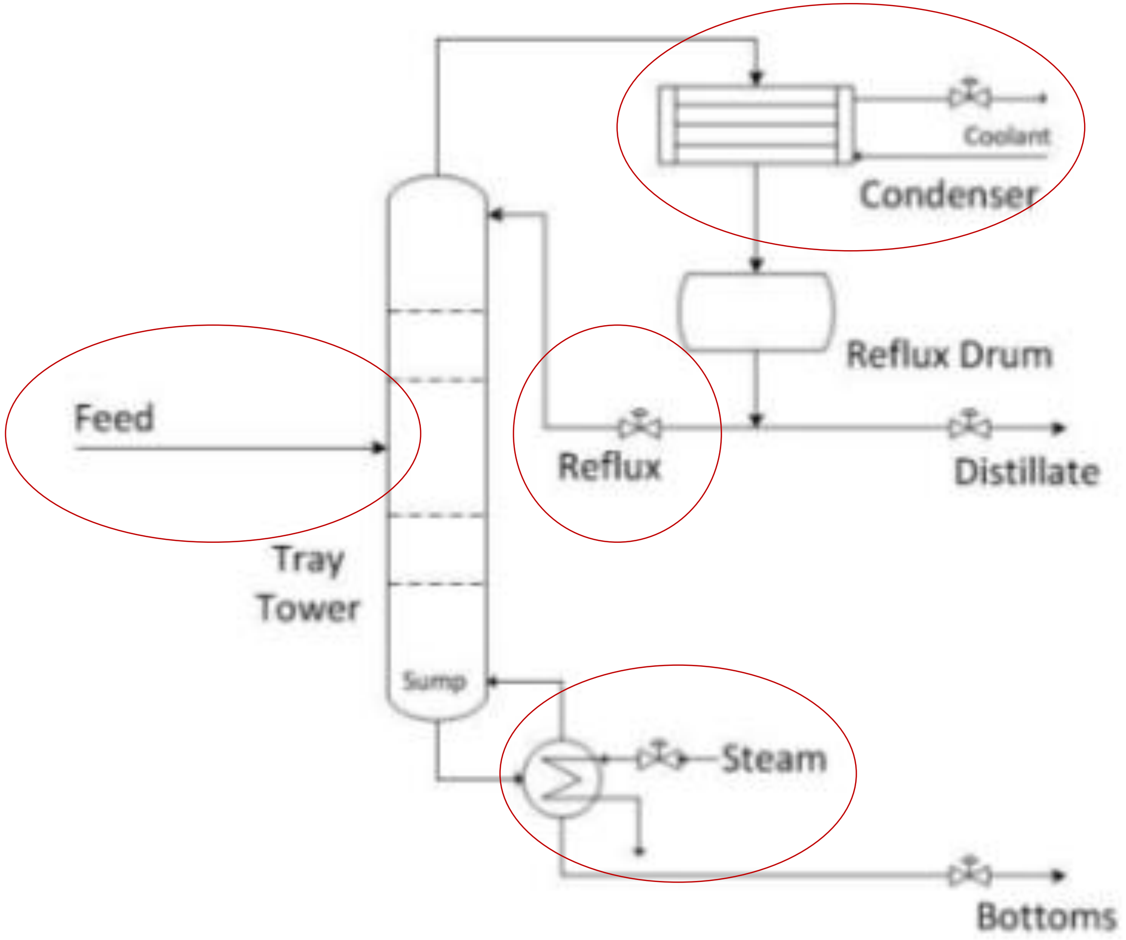
Energy Performance Improvement of Distillation Columns

- Feed location
- Feed conditioning
- Reflux ratio
- Overheads cooling
- Selection of reboiling heat source
- Operating pressure
  - ✓ Increase P to debottleneck condensers (higher process temp)
  - ✓ Reduce P to debottleneck reboilers (lower process temp)
  - ✓ Pressure effect on flooding depends on service
    - E.g. Higher pressure debottlenecks De-C4 and heavier
    - E.g. Lower pressure debottlenecks De-C3 and lighter
- Temperature profile
  - ✓ Side condensing
  - ✓ Side reboiling



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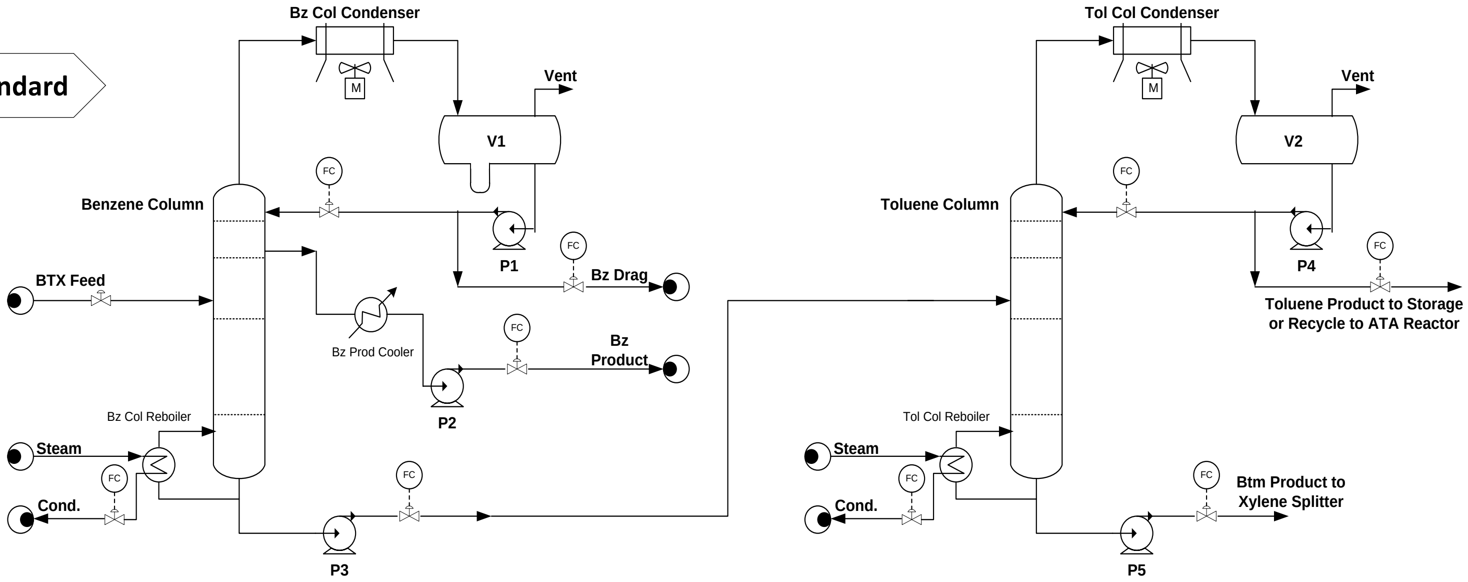
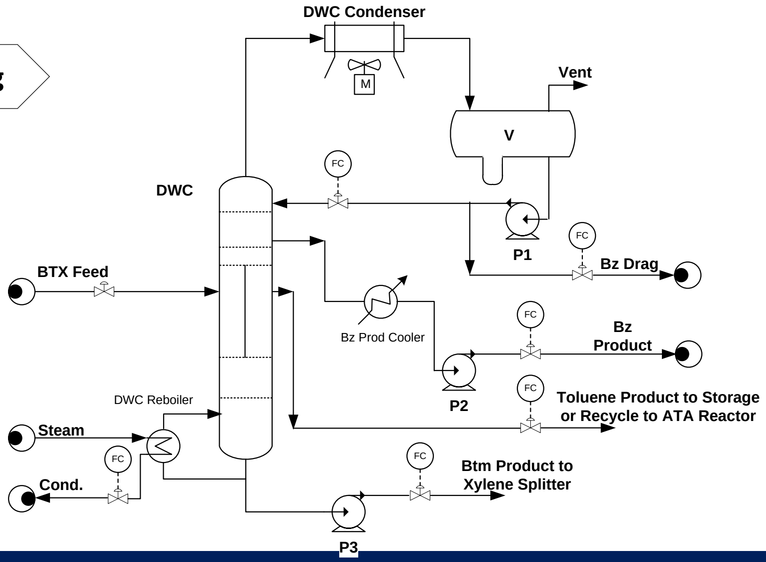
Divided Wall Column

Standard



Leading



- Saves capital cost in grass-roots application
  - ✓Only need one column with ancillary equipment
  - ✓Requires less plot space
- Up to 30% capital cost saving for a grassroots application
  - ✓Lower plot space and equipment
- Product yields / specifications same as base case
  - ✓DWC makes 3 fully purified products
- Offers operational benefits
  - ✓Eliminates the use of one column. Combines 2 columns in 1 shell
  - ✓Need to control only one column
  - ✓Less hydrocarbon inventory to handle

DWC: Applications

- C4 Isomer Separation
- C5 to C7 isomer splitting in naptha processing
- Butane splitting in NGL fractionation
- Pentane/Hexane/Heptane
- Depropaniser/Debutaniser
- Straight Run Naptha Fractionation

- FCC Naptha Fractionation
- FCC Debutaniser
- Reformate Fractionation
- FCC Debutaniser
- Reformate Fractionation
- Aviation Gasoline Production
- Napthalene Fractionation

- Xylene Fractionation
- Xylene Fractionation
- Benzene/Toulene/Xylene
- Benzene/Toulene/Ethyl Benzene
- Ethanol/water/Ethyl Glycol
- Ethanol/Propanol/Butanol separation

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Low Grade Heat Recovery

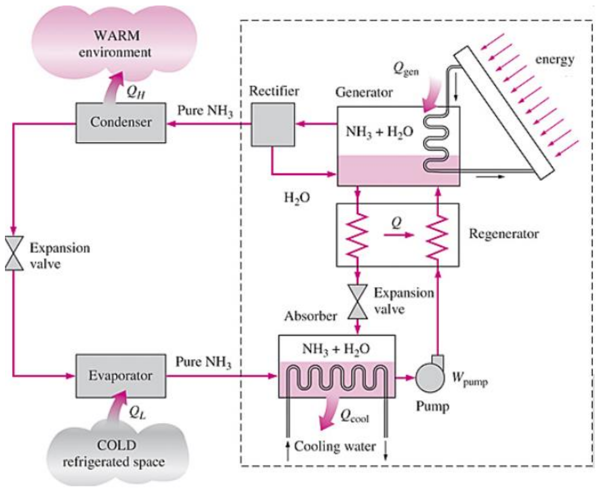
Traditional options are available for LGHR:

- **Direct heat recovery**
  - ✓ Preferred option
  - ✓ Lower investment cost in comparison to other options
  - ✓ Examples:
    - Column overhead against relevant streams (temperature depend)
    - Replace LPS on low temp. reboilers

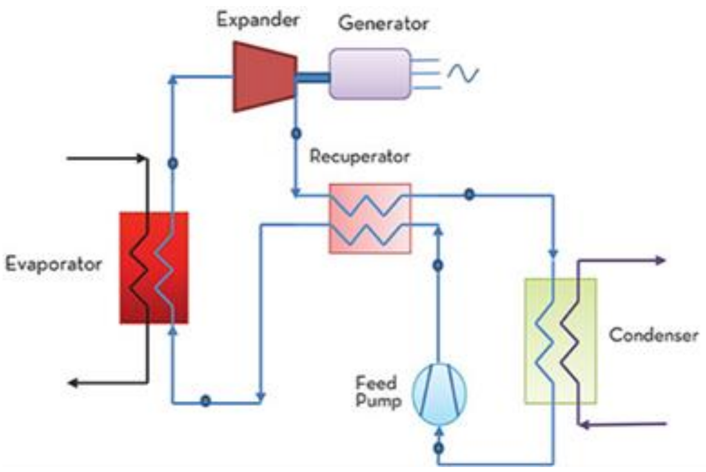
- **Condensing Turbine**
  - ✓ Power would be generated, but
  - ✓ Cooling water requirements would increase

- **Indirect heat recovery**
  - ✓ Hot water loop
    - Need to find enough heat sources and sinks to make it economic
    - Equipment: HW pump, multiple exchangers, piping can be significant

- **Absorption Refrigeration**
  - ✓ ARU produce chilled water in the range of 6 - 12°C
  - ✓ ARUs have been commercially available for many years and are installed on many sites worldwide
    - Where either power is extremely expensive or the heat source is effectively free of charge (e.g. LP steam that otherwise would be vented)



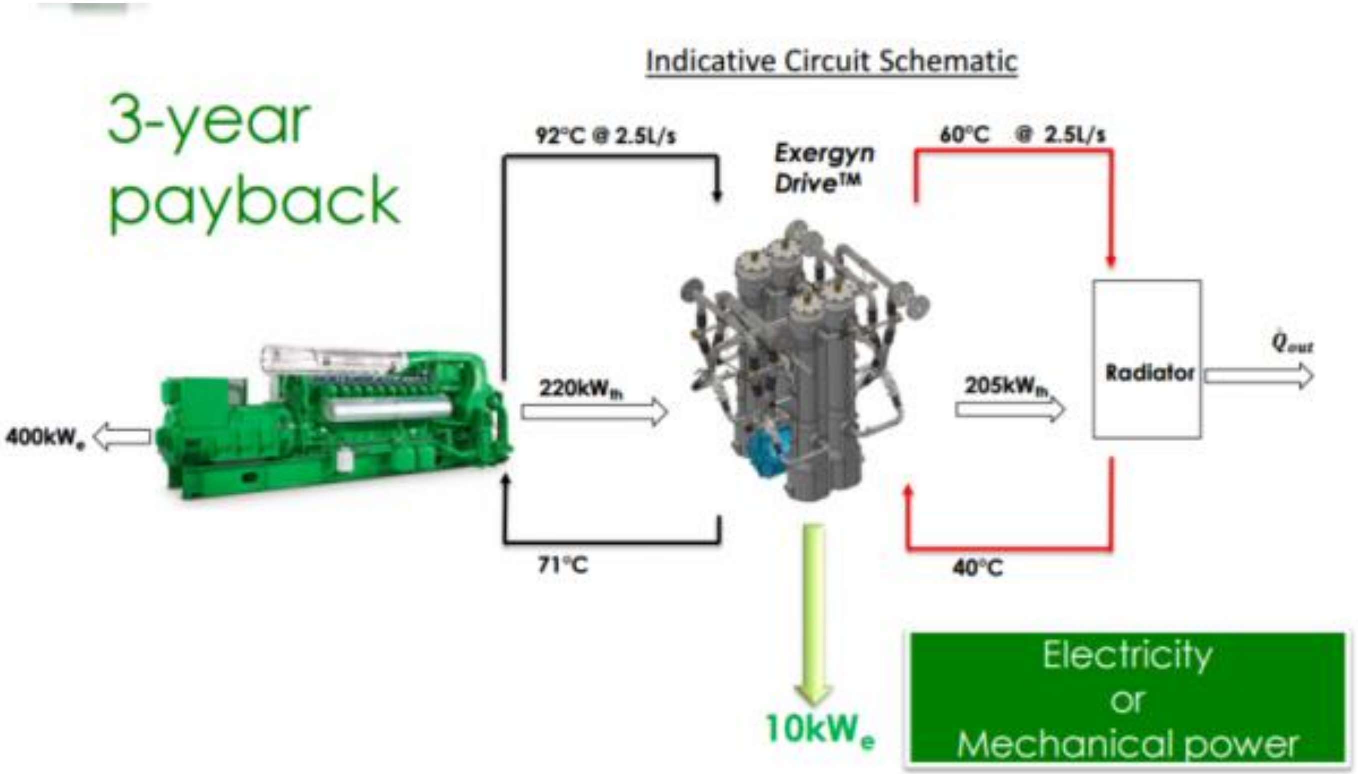
- **Organic Rankine Cycle (ORC)**
  - ✓ Effectively the same as the standard Rankine cycle but uses an organic fluid (CFCs, Freon, isoC5) with a boiling point lower than water
  - ✓ Efficiency between 10 to 20%
  - ✓ Selection of working fluid depends on:
    - Good stability at high temperatures
    - Availability
    - Cost



Low Grade Heat Recovery (cont'd)

LGHR Exergyn Drive™

- Utilises heat from <90C water
- Utilises specialised "Shape Memory" alloy
- Alternating inflows of hot hot/cold fluid stream create a rotary motion cycle which is then converted into electricity
- **10kW Modular design** with 20 year operating lifetime
- ½ **CAPEX** of traditional Organic Rankine Cycle system
- Bolt-on retrofit onto existing ORC / turbine exhausts
- **2-3 year payback**
- **NOT CURRENTLY AVAILABLE FOR DEPLOYMENT – Trialling since 2018**



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Low Grade Heat Recovery (cont'd)

Heat Recovery from Fluegas

Features

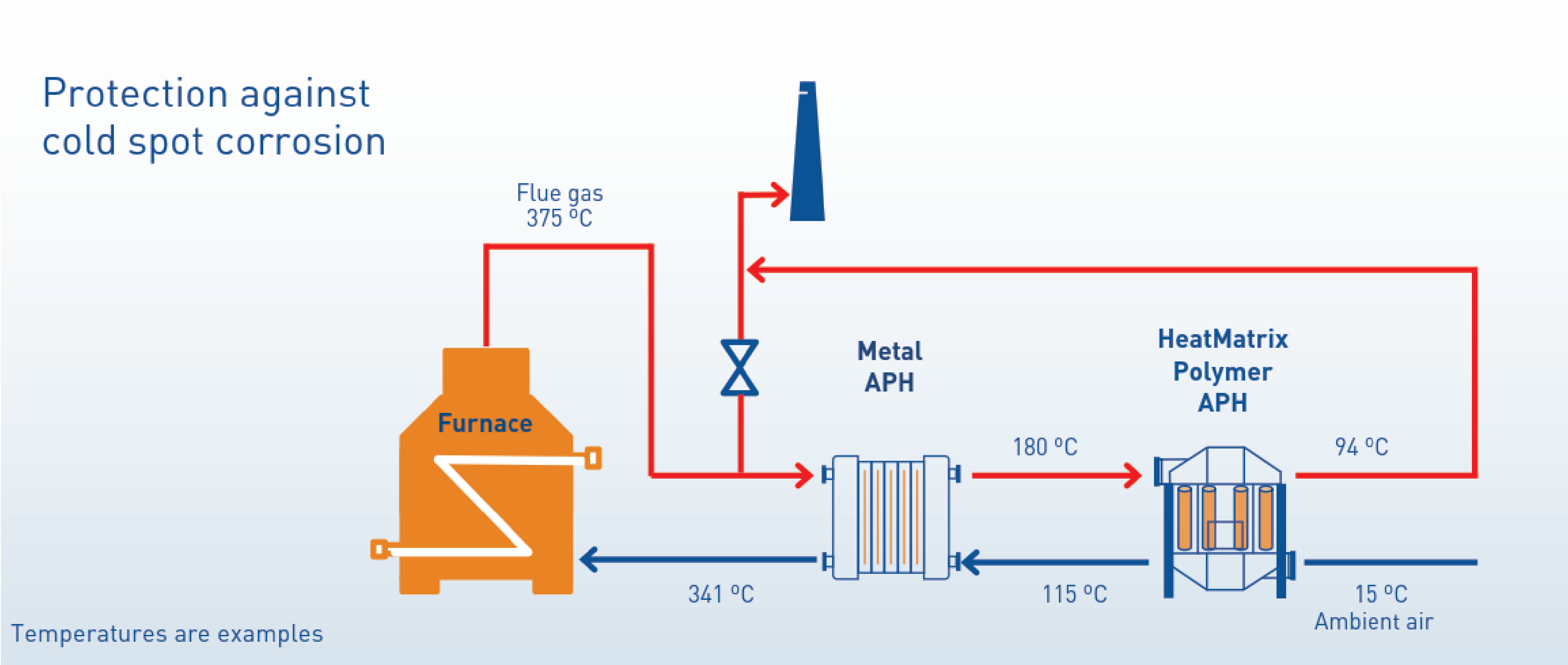
- Modular compact design
- Counter Current
- Scalable to any size
- Nozzles in any direction ü Optional spray cleaning

Operating range

- F: 5.000 – 500.000+ kg/hr
- T_{design}: 200 °C
- P_{design}: 150 mbar
- ΔP: ~6 mbar

- HeatMatrix APH -

Temp > 200°C: Hybrid metal & polymer APH



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Thank you