Key Trends in Green Hydrogen

Powering On Towards a Net Zero Future

NexantECA

August 2022

Biofuels Digest | DigestConnect

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Introduction to NexantECA

NexantECA, the Energy and Chemicals Advisory company, at a glance

Company

- Leading, independent provider of mission critical market, technical, environmental and commercial advice and intelligence to the global energy and chemicals sector.
- Highly complementary offerings combining deep intellectual capital and proprietary data and analytics.

50+ years of institutional knowledge

100+ Industry experts

12 countries worldwide with physical presence

Clients

Leading energy and chemicals operators, financial investors and advisors.

- Base Petrochemicals and Polymers
- C1 Chemicals and Fertilizers
- Intermediate and Specialty Chemicals
- Downstream Oil
- Gas, Midstream and Infrastructure
- Biorenewables and Circular Economy

Our Businesses

Three integrated solutions:

- Over 200 consulting engagements completed each year.
- Over 100 subscription reports published each year, providing analysis on more than 100 products.
- Online and in-house training, with 10-12 public training courses available throughout the year.

Locations

- Global knowledge and regional expertise; industry professionals based in key regions.

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Subscriptions and Reports - We have continued interaction with the industry, publishing over 100 reports a year

Markets and Profitability

Market, profitability and pricing analysis currently tracking 60 polymers, petrochemicals, feedstocks, refined products and fertilizers with forecasts to 2045:.

Markets
- Market Analytics
- Market Insights

Profitability
- Historic and Forecast Profitability

World Gas Model

Technology and Costs

Detailed technology analyses and process economics for existing, new technologies:

- TECH (formerly PERP)
- Biorenewable Insights (BI)
- Sector Technology Analysis
- Cost Curve Analysis

Special Reports

Special Reports addresses analyse issues of topical importance to the energy and chemicals industry.

Recent topics include:
- Recycling
- Sustainability
- Electric Vehicles

View all Markets and Profitability Reports

View all Technology and Costs Reports

View all Special Reports

www.NexantECA.com is our Client Delivery Portal – providing access to subscription content, individual reports purchases and Online Database access.

Overview of General Trends in Global Sustainability

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Sustainability is built on three key underlying drivers: Ecology, Society, and Economics

"We cannot despair of humanity, since we ourselves are human"

Albert Einstein, *The World as I see It* (1949)

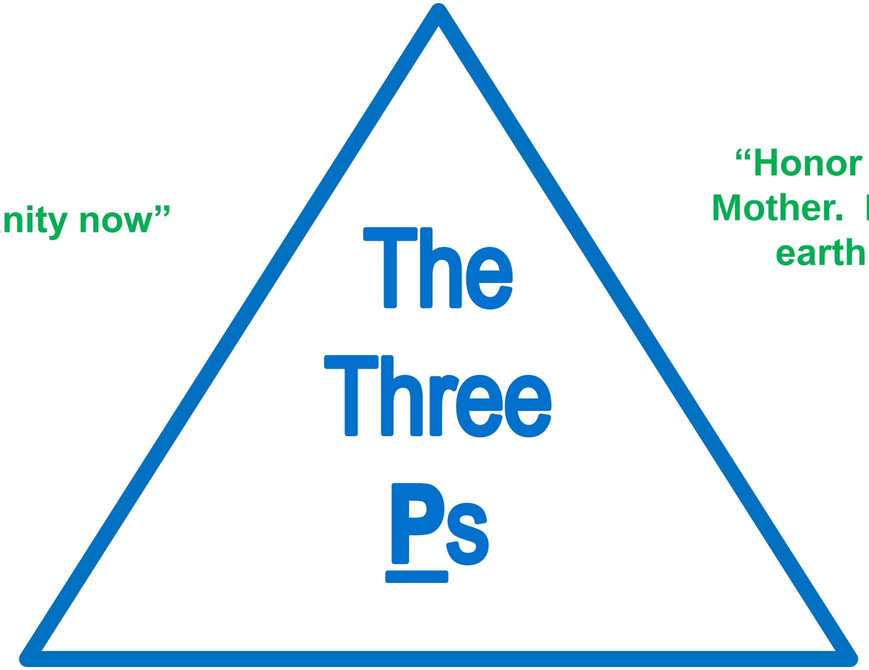
People

"Economics is on the side of humanity now"

Isaac Asimov

"Honor the sacred. Honor the Earth, our Mother. Honor all with whom we share the earth. Walk in balance and beauty"

Isaac Asimov



Profit

"Greed is Good"

Gordon Gecko, *Wall Street* (1987)

Planet

"There is No Planet B"

UN Secretary-General Ban Ki-moon (2013)

"Scientists are human. Unraveling the knots of nature's mysteries is a reward in itself; but even so, scientists like to hear the applause of the audience"

Isaac Asimov

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New sustainability standards no longer focus solely on bio-based carbon content have shifted to a focus on reducing greenhouse gases (GHGs) and overall carbon footprint – which biomaterials have a role to play

BETA
RADIOCARBON DATING
Consistent accuracy
Delivered on time
Beta Analytic

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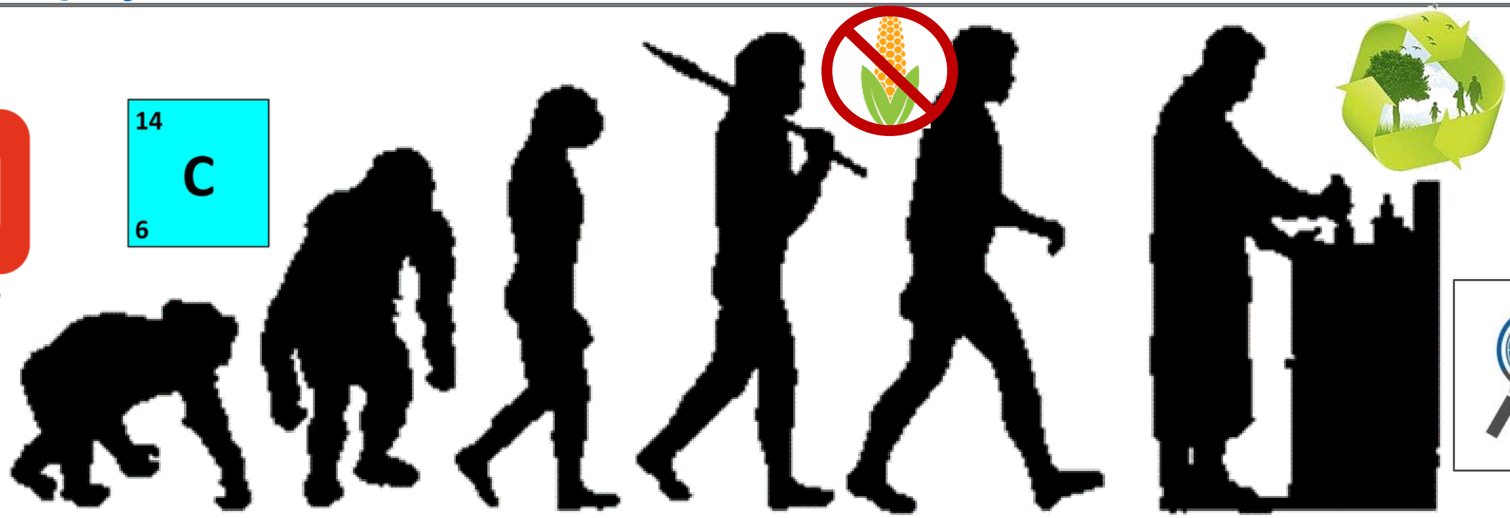


ISCC
International Sustainability & Carbon Certification

2000-2010: "Biobased Focus"

- Bio-based materials were the focus, and mostly biofuels (ethanol and FAME biodiesel are most of it)
- A C-14 test (ASTM D6866) is a good way to prove renewability
- Material segregation comes at a higher cost and carbon footprint but is necessary to maintain C14 levels
- Low oil prices generally spelled doom for renewables, as competitiveness reduced

2010-2015: "Non-Food Focus "

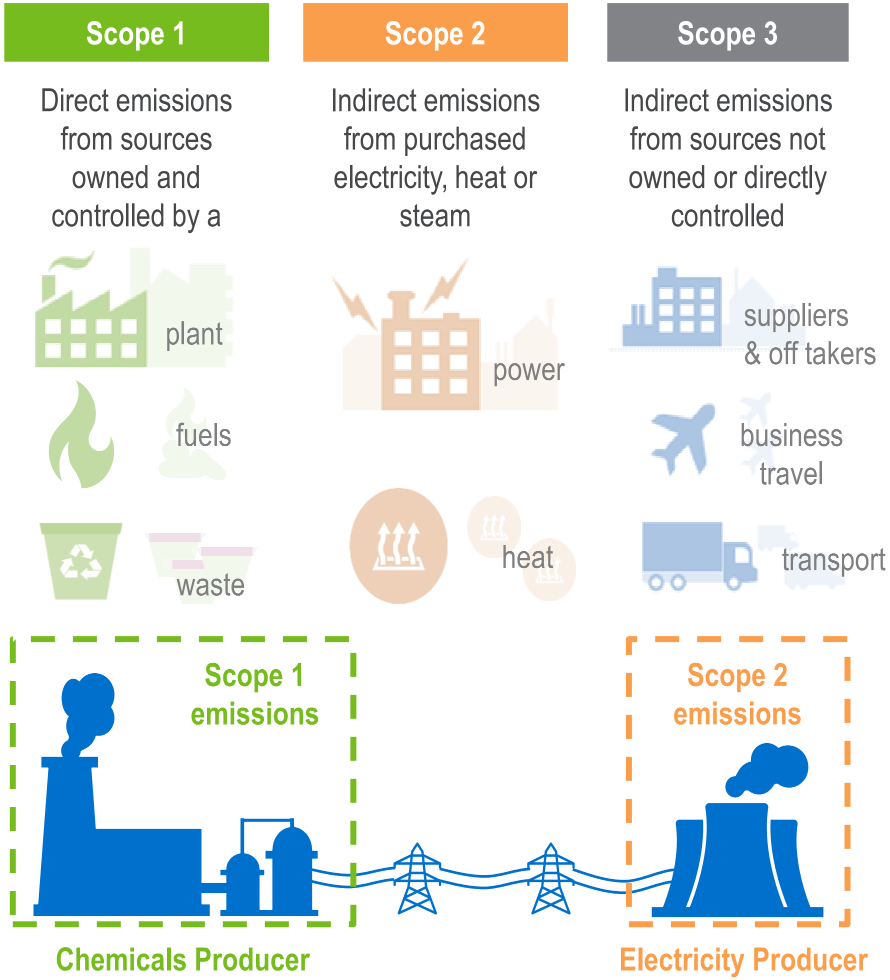
- Food vs. Fuels debate drives significant focus onto non-food sources – especially waste
- Bio-based materials remain in high focus, with mostly biofuels (ethanol and FAME biodiesel are still most of it, but HVO emerges)
- SAF begins to see significant Focus
- "Material Balance" Approach Emerges
- LCFS programs emerge incentivizing lower carbon intensities

2015-2022: "Carbon Intensity Focus"

- Carbon Intensity becomes major focus, supported by LCFS programs
- Many energy, chemical, logistics, and other industries have committed to carbon intensity goals – which include Net Carbon neutrality by the 2050-2070 timeframe
- 2019-2020 seen as a pivot point in consumer, industry, and finance appetite for what are seen as "dirty" projects

Scope 1, Scope 2, and Scope 3 emission categories are used to differentiate between direct and indirect GHG emissions with standards and certifications having been developed for reporting

To improve transparency and completeness in reporting, the Greenhouse Gas (GHG) Protocol established corporate standards and the concepts of Scope 1, 2, and 3 emissions



- **Scope 1** emissions are direct emissions that occur from sources controlled or owned by the reporting company
  - These can be the emissions from combustion of fuels, process emissions or fugitive emissions
  - The GHG Protocol does not include biomass combustion in Scope 1
- **Scope 2** emissions include the indirect emissions from the generation of purchased electricity consumed by the company
  - Purchased electricity is defined as electricity that is purchased or otherwise brought into the organisational boundary of the company
  - These emissions occur at the facility where the electricity is generated
- **Scope 3** includes all other indirect emissions, the emissions which are a consequence of the activities of the company but occur from sources not owned or controlled by the company
  - Scope 3 emissions are optional to report under the GHG Protocols reporting standard. Entities often narrow the inclusion criteria for Scope 3 emissions to allow for calculability

Certifications have developed to cover the full spectrum of emissions

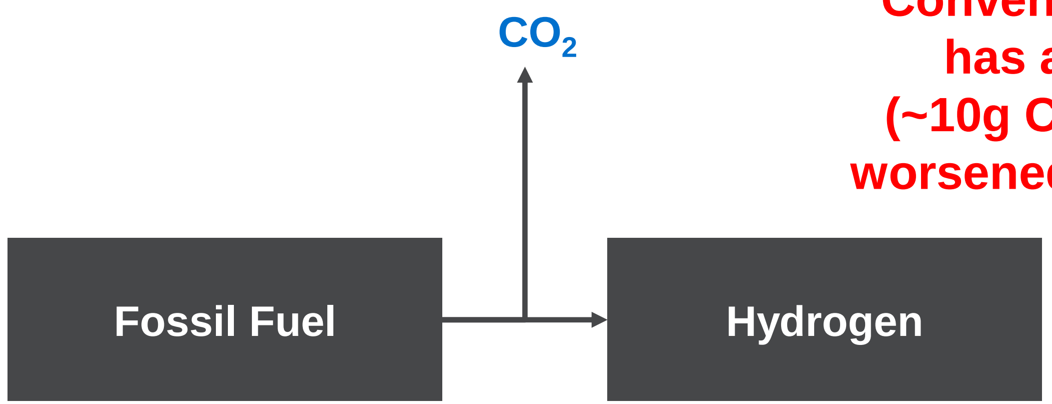
- The **GHG Protocol** establishes comprehensive global standardised frameworks to measure and manage GHG emissions from private and public sector operations, value chains and mitigation actions
- **CDP** is a not-for-profit charity that runs the global disclosure system to assist entities in managing their environmental impacts
- The **ISCC's** objective is to contribute to the implementation of environmentally, socially and economically sustainable supply chains

Overview of Trends in Hydrogen

Why is current industrial or “grey” hydrogen so “dirty”? Here’s how to make hydrogen from fossil fuels:

You start by taking something carbon rich…

Conventional hydrogen has a very high CI (~10g CO2 eq per g H2) worsened its very low MW

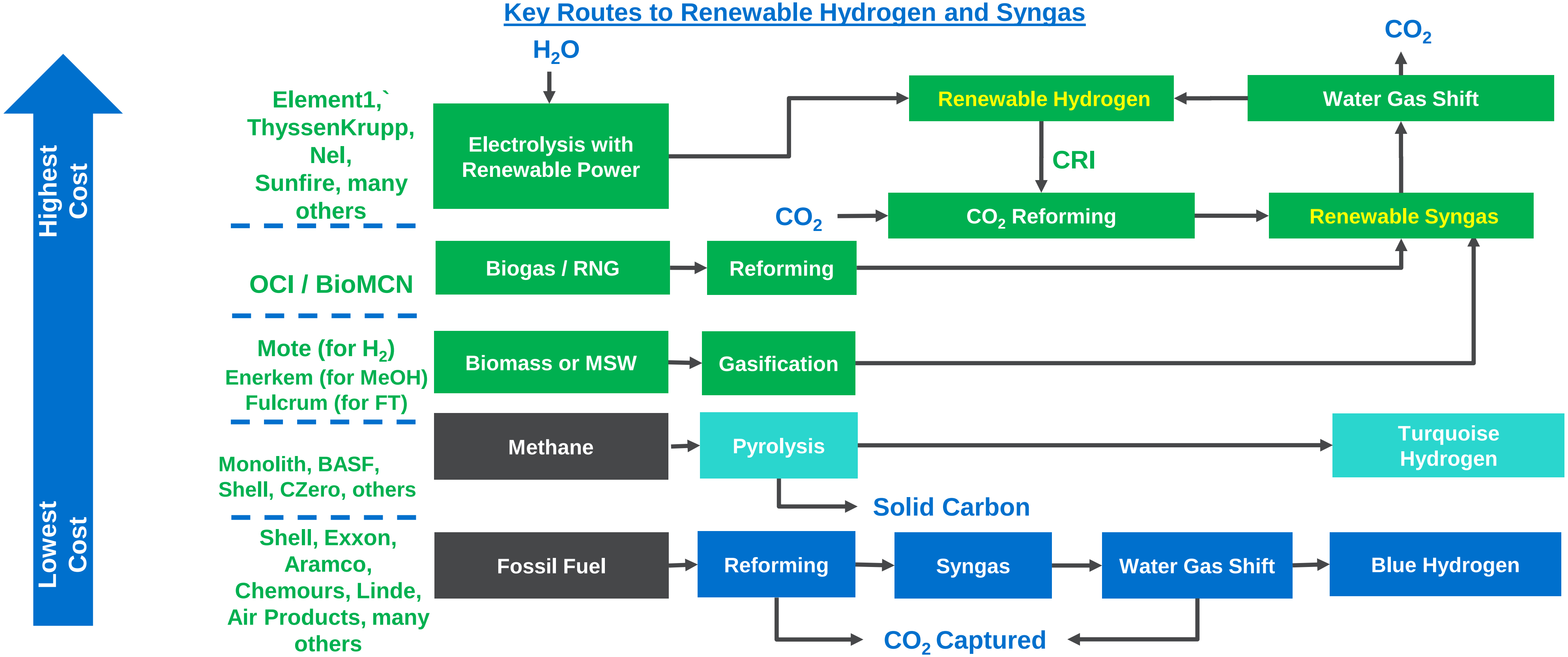


…and emitting all the carbon as CO_2

Adding carbon capture (via pre-combustion and post-combustion) to “grey” hydrogen is one way to deal with this and produces “blue” hydrogen, but be careful – carbon capture is highly energy intensive, so depending upon the overall carbon footprint and carbon intensity of the energy source Scope 2 emissions MAY be increased more than Scope 1 emissions are reduced

Renewable Hydrogen and Syngas are a key lynchpin to decarbonize fuels, feedstocks, and chemicals supply/value chain via viable pathways to reduce overall GHG emissions

Key Routes to Renewable Hydrogen and Syngas



Other pre-commercial routes under development include:

- Thermocataltytic Water Splitting – (OMC, Sandia CR5, ETH, etc)
- Biofuel reforming (ethanol, DME etc) – (Golü, Oberon, etc)

Other very early-stage routes with interest include

- Biological Production (e.g.,, Algae)
- Photocatalytic water splitting (e.g., artificial leaf)

Chloralkali production can also produce renewable hydrogen (depending upon the energy source, but is not green hydrogen by default)

Renewable hydrogen and/or syngas can be used to produce ammonia, methanol, acetic acid, FT Liquids, and other hydrogen, syngas, and/or CO based chemicals

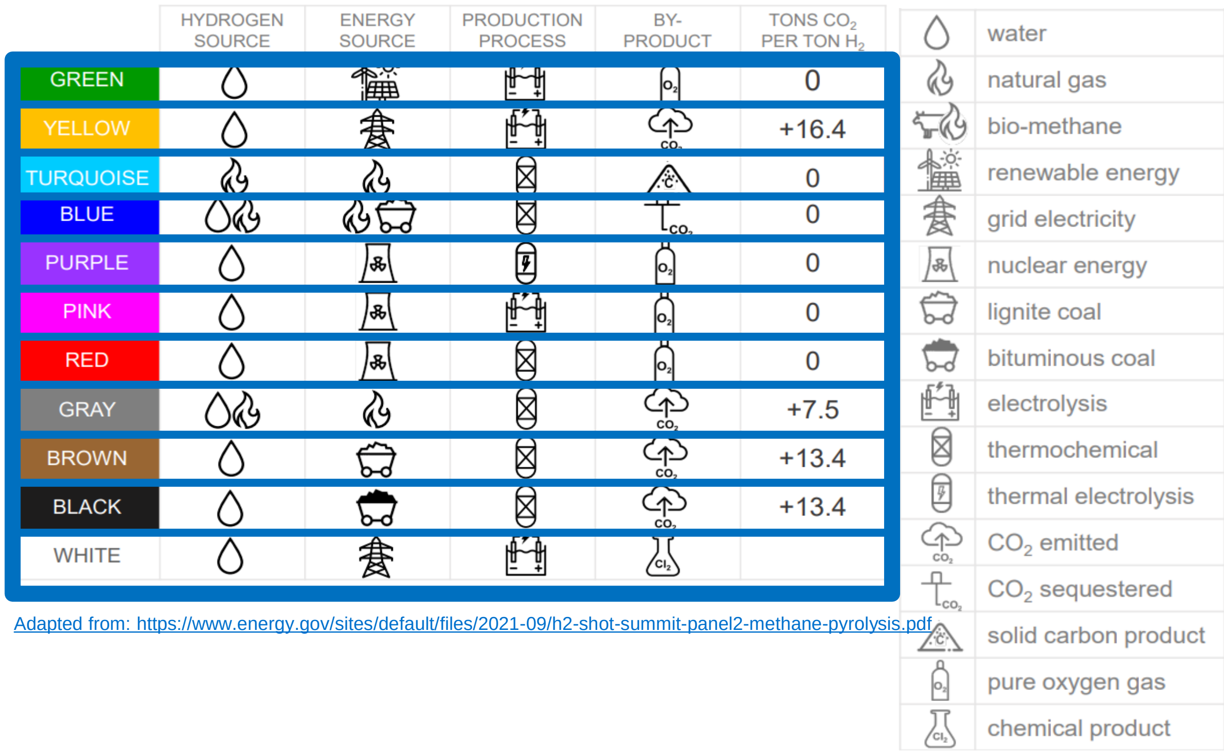
- CO2 reforming offers a CO2 Utilization option with access to large scale downstream markets for CO and syngas-based chemicals such as methanol, acetic acid, and FT liquids
- CO2 utilization and/or storage remains the most significant hurdle to the proliferation of carbon capture technologies

Electrolysis is a commercially proven clean technology, as there is no CO_2 produced during production, but the source of power supply is very important to the overall carbon footprint

Many Options exist for Low CI Power, with different sustainability profiles:

- Highly Sustainable, Low CI
  - Solar Photovoltaics (PV)
  - Wind (Onshore/Offshore)
  - Geothermal (Organic Rankine Cycle)
  - Tidal and Ocean Thermal
- Lower CI, but with Sustainability Concerns
  - Hydroelectric (Dams, Run-of-River, etc.)
  - Incineration
    - Biomass (Various Fuels/Feedstocks)
    - WTE
- Non-renewable but Low CI
  - Commercial Nuclear (Light Water Reactors and Small Modular Reactors)

Similarly, the different colors of hydrogen have different implications for the CI

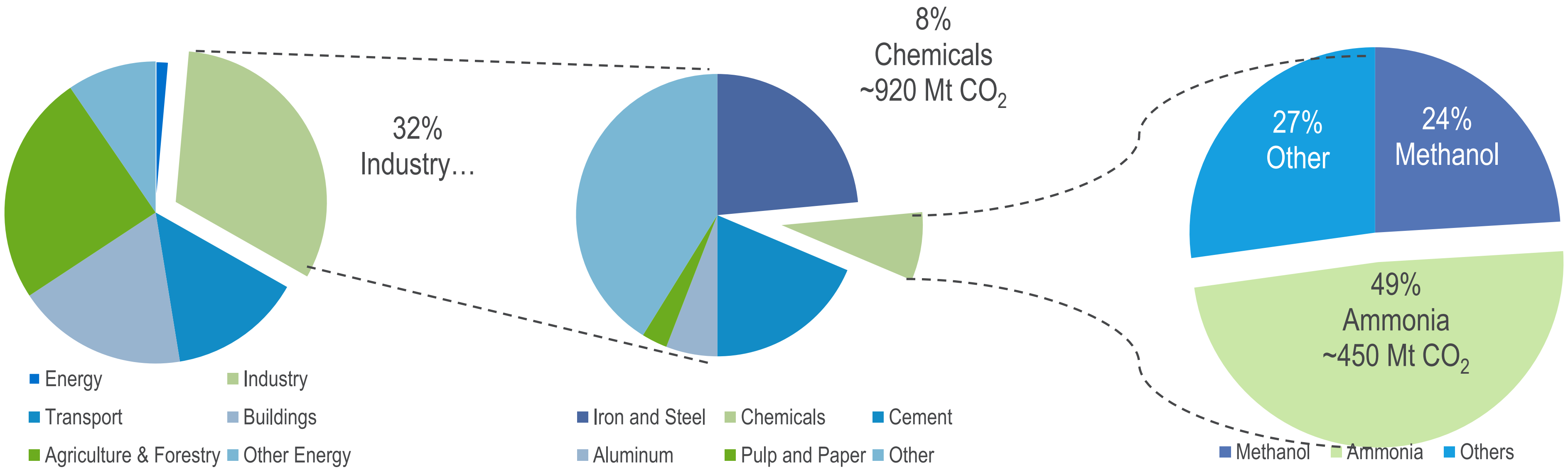


Adapted from: https://www.energy.gov/sites/default/files/2021-09/h2-shot-summit-panel2-methane-pyrolysis.pdf

With "must run" power plants status granted by national/state regulators, significant solar PV and wind capacity has and is coming online into the future—with very competitive levelized costs to incumbent production and supported for demand responsiveness by competitive energy storage on a levelized cost basis as well. WTE is falling out of favor due to (among other issues) concerns over particulate emissions and fossil materials contained within the waste streams

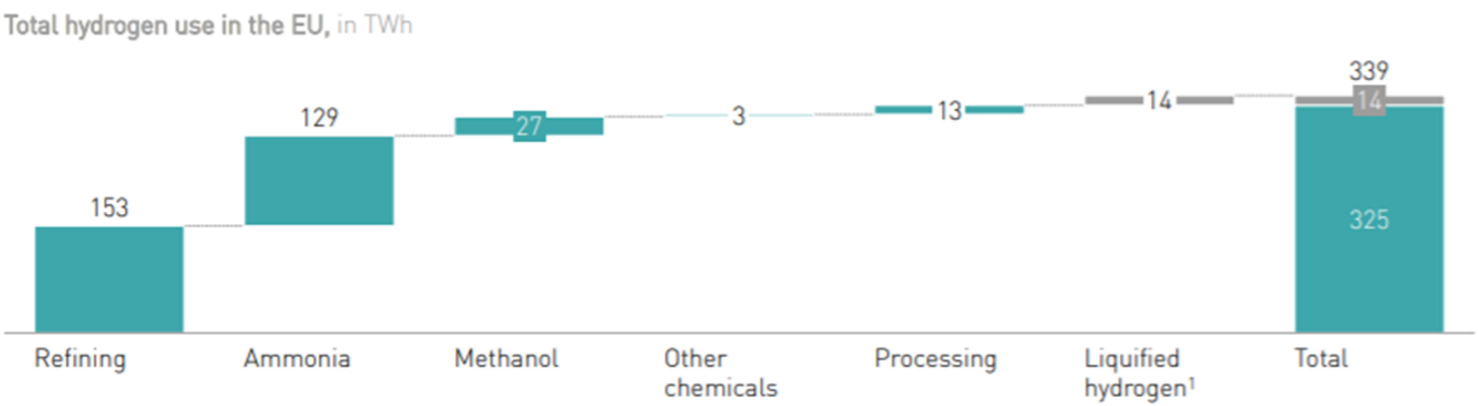
Global chemical emissions are dominated by the production of “grey” hydrogen and syngas

Annual Global GHG Emissions by End-Use | **Annual Global Industrial GHG Emissions by Sector** | **Annual Global Chemical Industry CO_2 Emissions by Product**



Sources:
IEA World Emissions Dataset, 2021
IPCC AR5 Working Group 3 Report (2014)

Hydrogen Use in the Chemical Industry
(Source: IEA.org)



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While Methanol and Ammonia have larger implications beyond just their large existing markets, Low Carbon Intensity Hydrogen's Implications Have the Potential to be the Most Far Reaching

Methanol – high interest and high activity

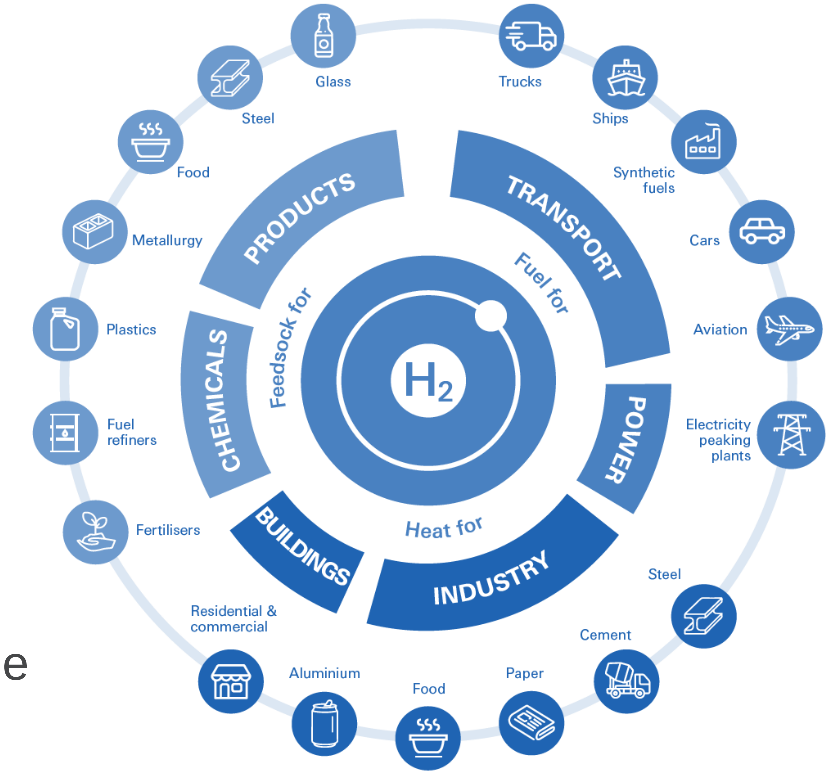
- Significant Interest as a Marine fuel
- Potential feedstock for olefins (via MTO)
- Potential feedstock for fuels (MTG or MTO+ATJ)
- MSW-based already commercial in Canada
- Biogas-based already commercial in Europe
- Power-to-Methanol commercial in Iceland

Ammonia – less activity but high interest

- Potential to reduce fertilizer carbon intensity
- Potential as a hydrogen carrier/virtual hydrogen pipeline

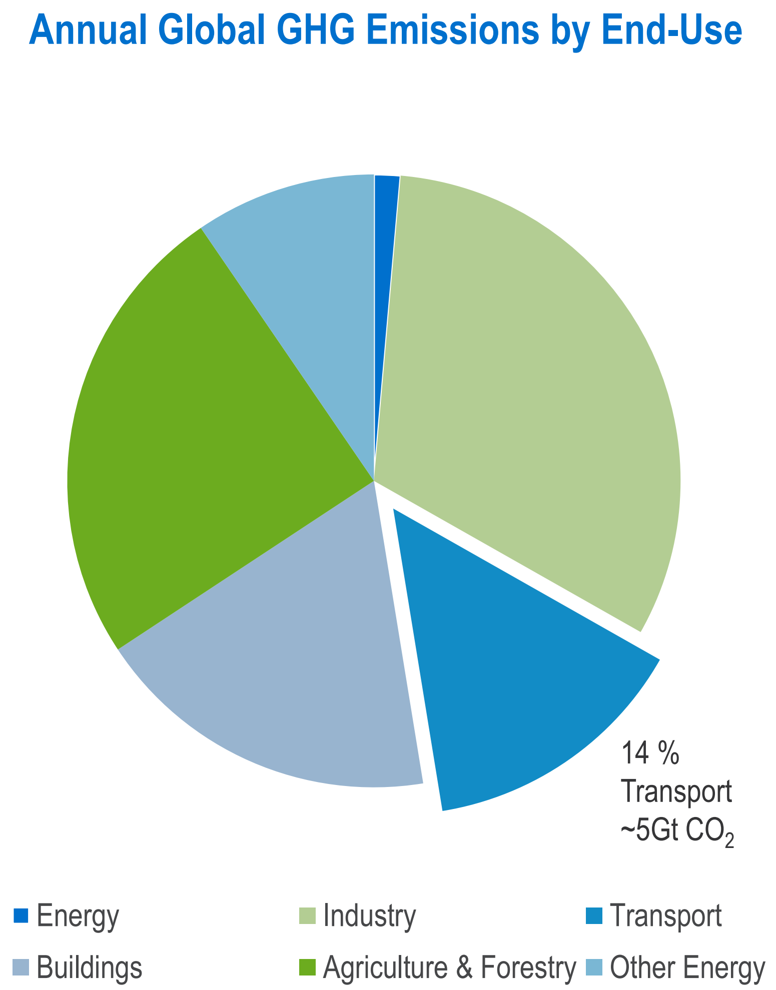
Hydrogen – a key enabler of fuels and chemicals

- Direct use as a fuel is limited, but maintains interest:
  - Terrestrial fuel cell vehicles
  - Airbus developing Hydrogen Plane by 2035
  - Potential for marine fuel
- Feedstock for renewable fuels (e.g., HVO)
- Feedstock for conventional fuel refining and chemicals



Methanol and Ammonia's low prices have represented the largest hurdle to development of replacements—however as we inch closer to a time when emissions have a cost and impact on profitability, that barrier is falling rapidly

A significant percentage of global GHG emissions is due to transportation and mobility – different types of transportation have different outlooks for sustainability and biofuels



Sources:
IEA World Emissions Dataset, 2021

Terrestrial Vehicles

- Includes trains, busses, cars, and trucks
- Significant effort and focus on decarbonization through alternative fuels—particularly ethanol and diesel replacements.
- Over the long-term expected to be addressable market by EVs

Marine Vehicles

- Includes container ships, bulk carriers, oil tankers, barges, and other water-bound vehicles
- Significant effort and focus on decarbonization through alternative fuels—particularly diesel, ammonia and methanol
- Over the long-term significant parts of the market are expected to be addressable market by EVs

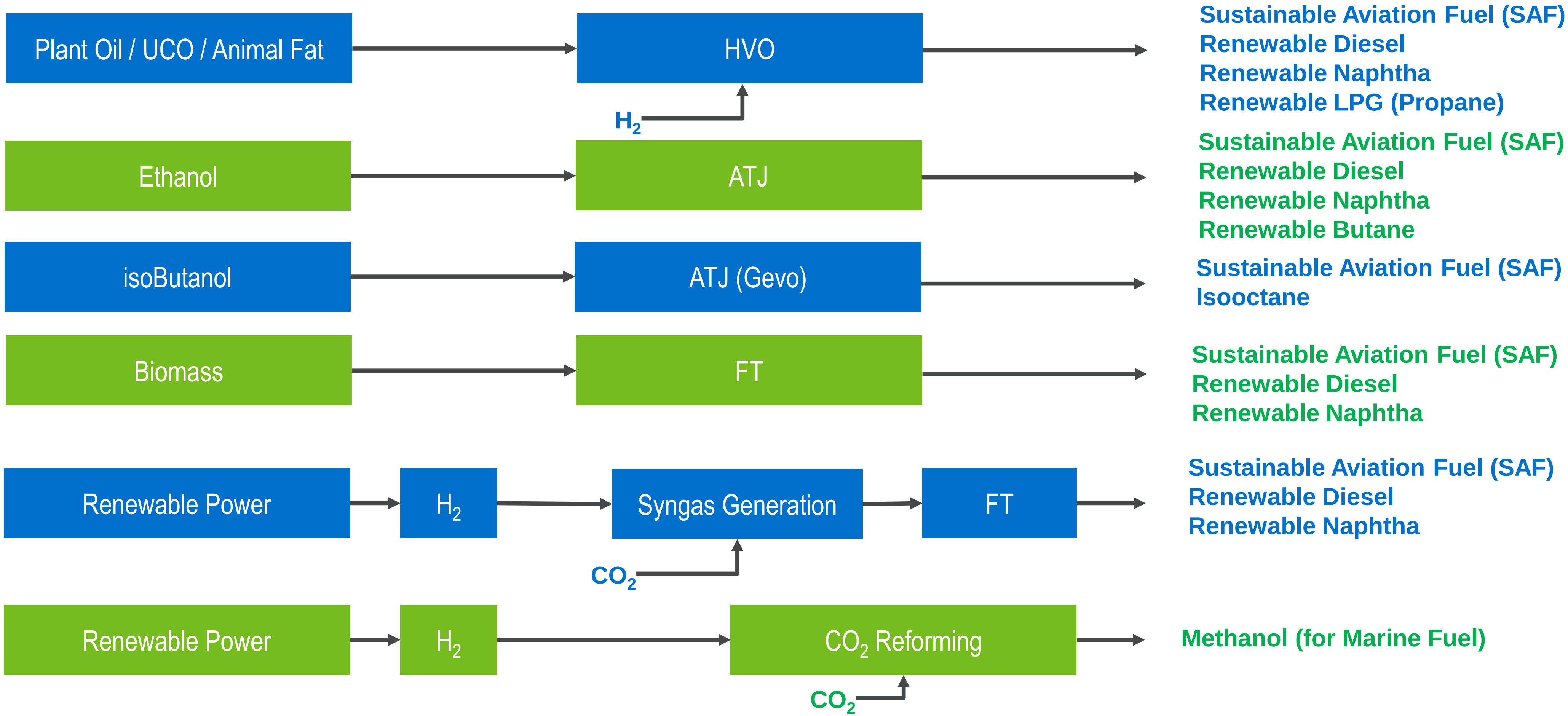
Aviation

- Includes planes, jets, and helicopters
- Significant effort and focus on decarbonization through alternative fuels—particularly HVO, FT, and ATJ routes
- Over the long-term **not** expected to be addressable market by EVs

More and more energy companies are turning to coprocessing HVO at their refineries

ATJ, PtL, FT, and other Low CI technologies are seeing significant interest – many of the products are the same – primarily driven by demand for SAF and Renewable Diesel– Though Marine interest is high too

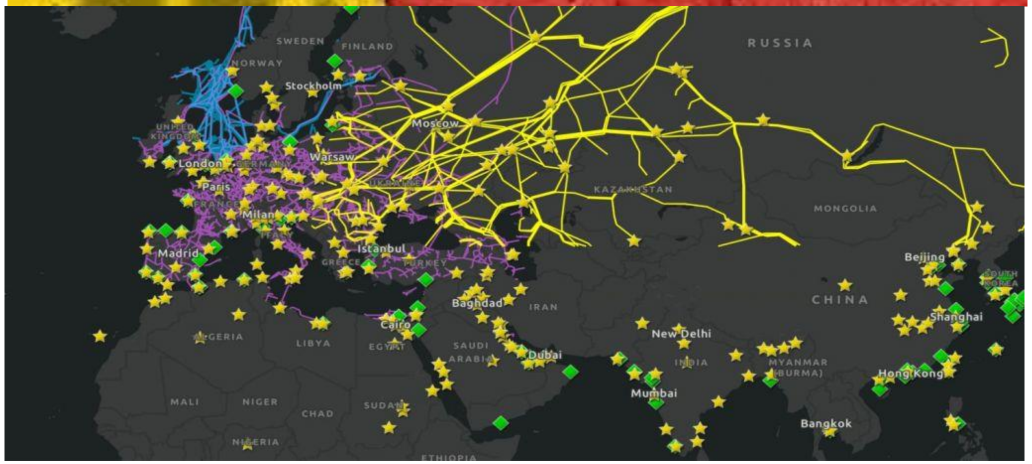
Byproduct renewable naphtha from HVO and other processes (in addition to use as a blendstock for fuels) is also seeing utilization as a feedstock for renewable chemicals



ATJ is seen as the next lowest hanging fruit after HVO while PtL is seen as the most impactful, meaning there may be a large opportunity for Sustainable Brazilian ethanol and the highly renewable grid offers benefits for PtL

The Russian invasion and war in Ukraine and its response has had a profound impact on European and Global Markets – particularly for energy, fertilizer, and related downstream sectors

- This has upended gas supplies in Europe (the main feedstock for hydrogen), raising prices to astronomical levels. Currently, biogas is cheaper than natural gas in Europe—which until a short time ago went for a premium. This means green hydrogen produced by switching to biogas is less expensive – though there is limited feedstock available, and availability is regionally specific
- The high price has improved economics for other routes as well, and projects are moving forward – particularly for electrolysis
- "All-hands-on-deck" situation for solutions and local production as a security of supply issue– including coal and other renewables
- Some renewables also impacted those based upon particularly biofeedstocks that have been impacted– natural oils and grains



The current aggression started in Spring of 2022 – there hasn't yet been a winter in the EU with reduced Russian gas, and winter is coming

Conclusions

Major end-use applications for hydrogen include refining, ammonia, methanol, specialty chemicals plus increased market demand growth from power generation, transportation, mobility, and other "energy carrier" uses

Industry	Key Applications	Supply Systems	Current H_2 Volumes (est.)	Likely Direction of Green H_2 Volumes - 2050
	• Power generation • Heat treating laboratories	• Small on-site • Cylinders • Tube trailers • Liquid H_2	Low <5 mm scfd	↑
	• Thin-film solar • Semi-conductors	• Tube trailer • Liquid H_2 • Small on-site		↑
	• Float glass manufacturing	• Liquid H2 • Small on-site	Medium 5-15 mm scfd	↑
	• Chemicals • Biofuels	• Pipeline • Large on-site		About the same
	• Hydro-processing	• Pipeline • Large on-site	High 30-20+mm scfd	↓

Each approach has pros and cons – some are more likely near-, short-, and medium-term solutions, while others are likely to be seen only in a longer timeframe

Increasing Technical Complexity, Capital Costs, Emissions Reductions

Increasing Commercial Readiness

	Technology Advantages	Technology Disadvantages	Technology Outlook
Feedstock Switching (e.g., RNG)	• Multiple Options emerging • Little to no infrastructure changes are required	• Current available volumes are limited • Current regulations, credits, other incentives, and industry demand are pulling potential feedstocks towards fuels markets and driving prices high • Dependent upon upstream technology to "fix the problem	Currently the low hanging fruit. The only limit is the supply—but additional volumes are expected as large growth in capacity is planned. Expected to be a go-to short term solution
Carbon Capture	• Can be used alone or in conjunction with other solutions • Can reduce Scope 1 emissions to at or near zero • May allow for other pollutant capture depending upon capture technology • Technology is "bolt-on", requiring no changes to process	• Scope 2 emissions are not reduced • Generally large energy requirements—which can increase Scope 2 emissions depending upon the source • Storage (and length of time of storage) is a contentious issue	Despite mixed reactions surrounding its efficacy as a solution, this appears to be a current focus of the energy majors as a way to deliver medium term solutions while still using fossil sourced oil and gas. Problem remains of storage or utilization of captured carbon.
Electric Water Splitting with Renewable Power	• Can be used alone or in conjunction with other solutions • Can be used for non-continuous applications (e.g., vehicle refueling)	• Requires new build / little overlap in existing infrastructure • Requires significant power, which must be renewable • Dependent upon upstream technology to "fix' part of the problem	Many developers are currently working on this in various phases of development and scales. Significant focus on downstream applications: emethanol and eSAF
Biomass Gasification	• Potential for low cost feedstocks • Most economically competitive currently	• Many are still under development and not yet commercial or not widely proliferated • Requires new capacity / value chain • Most hydrogen produced in this way is used captively	Significant focus on methanol, ammonia, and FT SAF which may include green hydrogen as an intermediate. Very few (including Mote) are focused on this for hydrogen as a product

Feasible, viable, and profitable solutions for decarbonization aren't in competition with each other, rather will be effectively utilized together to achieve GHG emissions targets and goals

- **Costs are emerging for "dirty" production:**
  - Regulatory/Taxes
  - Loss of access to financing
  - Negative market view
- **"Net-Zero" pledges by 2050 require substantial change to achieve**
- **One solution alone will not be able to deliver**
- **We are increasingly reaching the point of emergency regarding the climate**
- **"All-hands-on-deck" situation for solutions**
  - To achieve "Net-Zero" ambitions
  - To meet domestic needs in Europe due to gas restrictions

Sustainability is no longer being pushed by "green activism" alone – it is now a large consideration regarding long term profitability and competitiveness

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Energy and Chemicals Advisory

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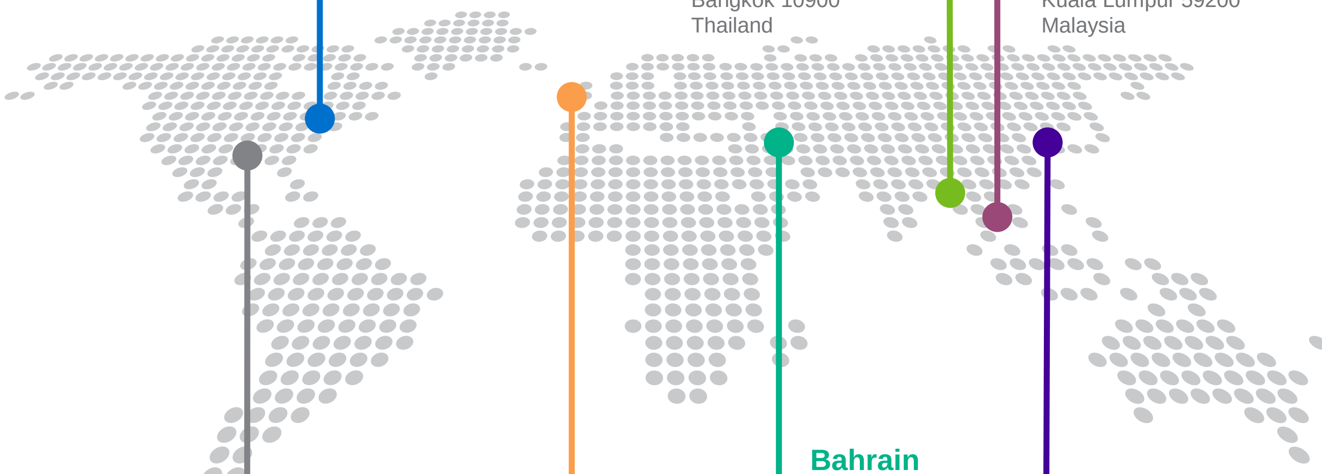
CONSULTING

SUBSCRIPTIONS AND REPORTS

TRAINING

NexantECA partners with clients to help them navigate the big global energy, chemicals and materials issues of tomorrow. We provide independent advice through our consulting, subscriptions and reports, and training businesses using expertise developed in markets, economics and technology through our fifty years of operation. We are entirely dedicated to supporting sustainable development of the industry and provide expert advice with efficiency, speed, and agility.



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Disclaimer

Appendix

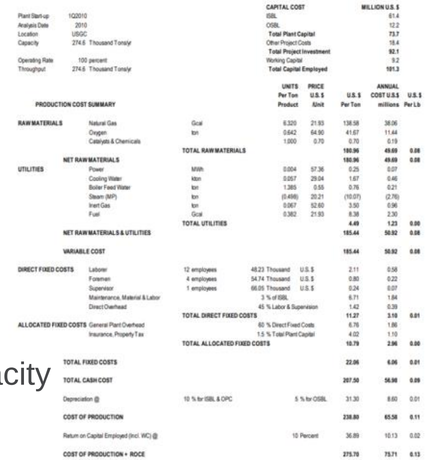
A

Key Offerings of Interest

For other individual chemicals or whole value chains, NexantECA can offer further analyses

Cost of Production Models:

- Many cost of production models for renewable or low carbon intensity chemicals and fuels can be found in NexantECA's ***Biorenewable Insights*** program, as well as supporting analysis including:
  - Technology Analysis
    - Process Descriptions
    - Process Chemistry
    - Process Flow Diagrams
  - Capacity Analysis
    - Exiting Capacity
    - Planned Capacity
    - Risk Adjusted Planned Capacity
  - Strategic Analysis

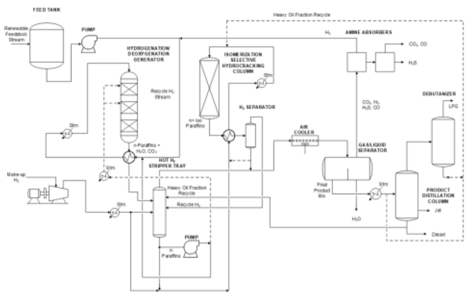


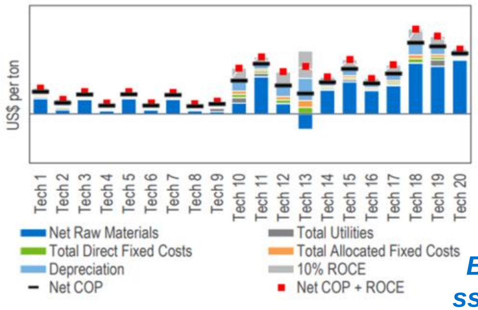
Plant Start-up	1Q2010
Analysis Date	2010
Location	USGC
Capacity	274.6 Thousand Tons/yr
Operating Rate	100 percent
Throughput	274.6 Thousand Tons/yr

CAPITAL COST	MILLION U.S. $
ISBL	61.4
OSBL	12.2
Total Plant Capital	**73.7**
Other Project Costs	18.4
Total Project Investment	**92.1**
Working Capital	9.2
Total Capital Employed	**101.3**

PRODUCTION COST SUMMARY			UNITS Per Ton Product	PRICE U.S. $ /Unit	U.S. $ Per Ton	ANNUAL COST U.S.$ millions	U.S. $ Per Lb
RAW MATERIALS	Natural Gas	Gcal	6.320	21.93	138.58	38.06	
	Oxygen	ton	0.642	64.90	41.67	11.44	
	Catalysts & Chemicals		1.000	0.70	0.70	0.19	
	TOTAL RAW MATERIALS				180.96	49.69	0.08
NET RAW MATERIALS					180.96	49.69	0.08
UTILITIES	Power	MWh	0.004	57.36	0.25	0.07	
	Cooling Water	kton	0.057	29.04	1.67	0.46	
	Boiler Feed Water	ton	1.385	0.55	0.76	0.21	
	Steam (MP)	ton	(0.498)	20.21	(10.07)	(2.76)	
	Inert Gas	ton	0.067	52.60	3.50	0.96	
	Fuel	Gcal	0.382	21.93	8.38	2.30	
	TOTAL UTILITIES				4.49	1.23	0.00
NET RAW MATERIALS & UTILITIES					185.44	50.92	0.08
VARIABLE COST					185.44	50.92	0.08
DIRECT FIXED COSTS	Laborer	12 employees	48.23 Thousand	U.S. $	2.11	0.58	
	Foremen	4 employees	54.74 Thousand	U.S. $	0.80	0.22	
	Supervisor	1 employees	66.05 Thousand	U.S. $	0.24	0.07	
	Maintenance, Material & Labor		3 % of ISBL		6.71	1.84	
	Direct Overhead		45 % Labor & Supervision		1.42	0.39	
	TOTAL DIRECT FIXED COSTS				11.27	3.10	0.01
ALLOCATED FIXED COSTS	General Plant Overhead		60 % Direct Fixed Costs		6.76	1.86	
	Insurance, Property Tax		1.5 % Total Plant Capital		4.02	1.10	
	TOTAL ALLOCATED FIXED COSTS				10.79	2.96	0.00
TOTAL FIXED COSTS					22.06	6.06	0.01
TOTAL CASH COST					207.50	56.98	0.09
Depreciation @		10 % for ISBL & OPC	5 % for OSBL		31.30	8.60	0.01
COST OF PRODUCTION					238.80	65.58	0.11
Return on Capital Employed (Incl. WC) @			10 Percent		36.89	10.13	0.02
COST OF PRODUCTION + ROCE					275.70	75.71	0.13

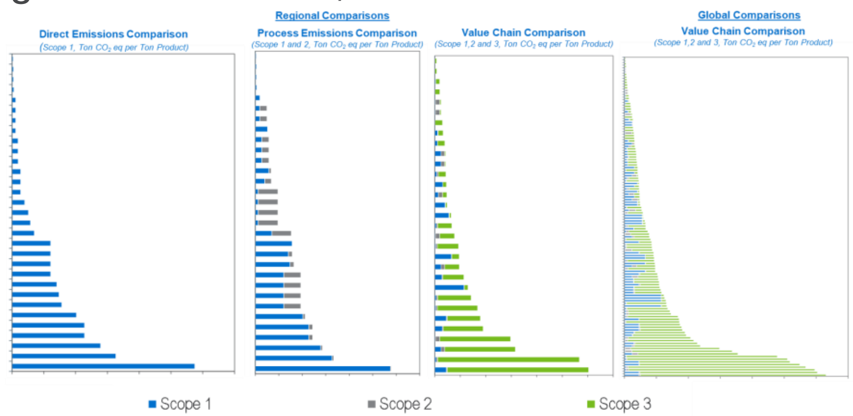
- Many cost of production models for conventional petrochemicals and fuels, can be found in NexantECA's ***TECH*** program (formerly PERP)





Carbon Intensity Analysis

- For any chemical currently covered at the Cost of Production model level in the **Biorenewable Insights** Program and/or the **TECH** Program, a carbon intensity model in a desired region or regions is available, as an add-on.



Market Analysis

- For many chemicals featured in the Biorenewable Insights and TECH programs, there is also market coverage (supply, demand, pricing) for the same chemicals in the ***Market Insights*** program, which has history and scenario-based forecasts of key market data

Biorenewable Insights
sslome@nexanteca.com

TECH
mcesar@nexanteca.com

Market Insights
xpeng@nexanteca.com

Some key recent reports related to Renewable Hydrogen– NON-COMPREHENSIVE: LAST 3 YEARS ONLY

Biorenewable Insights Program

- Biorenewable Insights: Cellulosic Feedstocks (2021 Program)
- Biorenewable Insights: HVO (2022 Program)—COMING SOON
- Biorenewable Insights: RNG (2022 Program)—COMING SOON (Update of 2019 Report)
- Biorenewable Insights: Ammonia (2022 Program)—COMING SOON
- Biorenewable Insights: Sustainable Aviation Fuel (SAF) (2021 Program)
- Biorenewable Insights: Biomethanol as a Platform Chemical (2021 Program)
- Biorenewable Insights: Hydrogen (2020 Program) – 2022 Update Coming Soon
- Biorenewable Insights: Municipal Solid Waste (MSW) as a Sustainable Feedstock (2021 Program)
- Biorenewable Insights: Renewable Power (2020 Program)
- Biorenewable Insights: Biocoal and BioCrude (2020 Program)

TECH Program

- TECH Blue Hydrogen (2021 Program)

Market Insights Program

- Market Insights: Hydrogen – 2022
- Market Insights: Hydrotreated Vegetable Oils – 2021
- Market Insights: Carbon Dioxide - 2021