Decentralised biomethane production from woody biomass

PyroCatalytic Hydrogenation for carbon-negative energy security

By Stephen B. Harrison

The 2026 crisis in the Middle East has deep transformational consequences within the region and beyond. Damage to the Ras Laffan LNG facility in Qatar has eliminated a significant amount of global LNG supply capacity. Internationally, the crisis has disrupted fertiliser and fuel supply chains and isolated major exporters from their long-standing offtakers.

With the benefit of hindsight, some might say this supply chain disruption was inevitable. The 12-day war in June 2025 clearly indicated the extent to which volatility was mounting in the region. Closure of Hormuz has been threatened in the past. And, due to security concerns, Suez Canal cargoes in 2025 were reduced by around 60% compared to 2023.

The nature and location of the next international flashpoint is not known, what is clear is that international energy flows are subject to changes triggered by geopolitical events. The world is entering a 'predictably chaotic' state.

A responsible transition

Since the end of the Cold War, the world has benefitted from globalisation and the 'peace dividend'. International trade of fuels has kept inflation under control by allowing energy commodities to be sourced from the lowest-cost worldwide location.

But the present and the future are clearly different. We are living in a new era. One where resilience, localised supply chains and energy security will be valued at a premium. But these objectives must still be achieved affordably, and with respect to the avoidance of long-term catastrophic events, such as climate change.

The time for local, resilient, climate-friendly energy security has come.

Home-grown biomethane

Local energy sourcing is a fundamental driver of supply chain resilience and bio-based energy is generally produced and consumed locally. A driver for this is that the volumetric and gravimetric energy density of the biomass feedstocks such as wood, grass, bagasse and maize is low, compared to liquid fuels such as gasoline or diesel.

Biogas, upgraded to biomethane, is one of the main bio-energy sources utilised today. Almost all biomethane is produced in anaerobic sludge digesters of various kinds. The feedstock is often a purpose-grown crop such as grass or maize. To balance continuous demand for energy with growing seasons, these feedstocks can be stored as silage in horizontal silos for time shifting from summer to winter months.

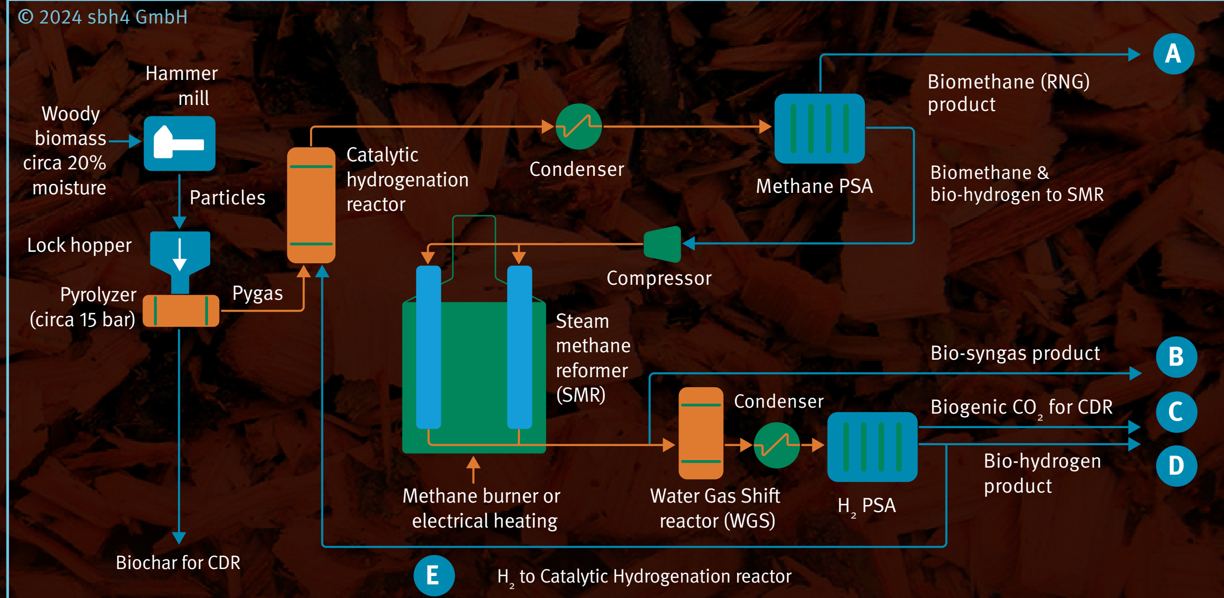
Farm waste from poultry, pig and dairy farms, sewage sludge and food waste from urban centres are generally available through the year and are also excellent feedstocks for biogas production.

Despite many efforts to adapt the anaerobic sludge digestion, this process has not yet been successfully deployed at scale for highly cellulosic feedstocks such as straw and waste wood. Technological breakthroughs in this field will unlock many stranded bio-energy sources.

Conversion of woody biomass to energy gases

Research into the conversion of residual forestry waste and other cellulosic post-harvest wastes has been ongoing for decades. Current technologies centre

G4 PyroCatalytic Hydrogenation (PCH) Process for Biomethane, Bio-hydrogen, Biogenic CO_2 and Biochar Production from Woody Biomass



1. Residual forestry waste (woody biomass) is milled to circa 5mm particles to enable thorough conversion in the pyrolyzer chamber
2. The ideal catalytic hydrogenation reaction is: $4C_6H_9O_4 + 28H_2 \rightarrow 15CH_4 + 16H_2O + 9C$
3. The catalytic hydrogenation reactor uses a de-risked, proven commercial catalysts and is a proprietary design with features to...
   - Manage heat distribution from the exothermic hydrogenation reaction to prevent zonal overheating
   - Manage the heat profile to prevent tars condensation in cooler zones
   - Ensure mixing for complete product conversion of pygas to biomethane
4. Circa 20% moisture in the biomass feed is beneficial and requires no additional drying beyond covered storage
5. Biochar is produced with circa 80% carbon content
6. Minerals (ash) that are contained in the woody biomass leave the process with the biochar
7. Methane from the catalytic hydrogenation reactor is converted to hydrogen in the SMR
8. Some hydrogen must to be recycled to the catalytic hydrogenation reactor to ensure sufficient hydrogen is available to convert carbon in the biomass to biomethane
   - Biogenic CO_2 (C) is always produced, due to the need to produce hydrogen for the catalytic hydrogenation reactor
9. The process can be designed, or adjusted during operation, to favour different products...
   - If bio-syngas (B) or bio-hydrogen (D) are the desired products, the total stream from the catalytic hydrogen reactor can be fed to the SMR
   - If bio-methane (A) is the desired product, the feed gases to the SMR can be minimised to produce only the amount of hydrogen required for the catalytic hydrogenation reactor
   - The ratio of bio-hydrogen plus biogenic CO_2 (C + D) to bio-syngas (B) can be adjusted according to the preferred product mix.

around various thermal techniques such as torrefaction, pyrolysis and gasification.

Often, the product from these technologies is syngas, which contains a high amount of hydrogen and carbon monoxide. A notable exception is Thermally accelerated Anaerobic Digestion (TAD), which has been developed by Biezel Green Energy in India to convert green crop residues to biomethane and hydrogen.

To unlock the woody biomass to biogas pathway, G4 Insights, in Canada, has developed and proved a proprietary process which converts cellulosic biomass to biomethane. Its technology pathway is referred to as PyroCatalytic Hydrogenation (PCH).

G4 PCH for low-cost biomethane

The key elements of PCH are:

1. Woody biomass feedstock preparation to create particles with dimensions in the order of 5mm
2. Pyrolysis of the biomass to create pyrolysis gas (pygas) and biochar
3. Recovery of the biochar as a valuable co-product
4. Conversion of the pygas and residual tars to biomethane in a proprietary catalytic hydrogenation reactor
5. Stream-splitting to recover a portion of the biomethane as product and feed the balance to a steam methane reformer (SMR)
6. Conversion of the biomethane to bio-syngas reformate in the SMR
7. Water gas shift (WGS) to convert carbon monoxide (CO) from the bio-syngas to hydrogen and CO_2

International Shipping of Hydrogen, Hydrogen Carriers, Hydrogen Derivatives and E-fuels

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	Compressed Hydrogen Gas	Liquid Hydrogen	Liquid Ammonia	Liquid Methanol	LOHC – Liquid Organic Hydrogen Carrier (MCH used as an example)	Liquefied Natural Gas (LNG)	Synthetic Aviation Kerosene (SAF)
Temperature for transportation and storage	Ambient	- 253 °C	- 33.3 °C	Liquid at ambient temperature	Hydrogenation:150 - 200 °C; Transported at ambient temperature; Dehydrogenation: 250 - 320 °C	–162 °C	Ambient
Pressure for transportation and storage	250 to 700 bar	Atmospheric pressure	Atmospheric pressure	Atmospheric pressure	Hydrogenation › 20 bar; transport at atmos-pheric pressure; dehydrogenation ‹ 5 bar	Atmospheric pressure	Atmospheric pressure
Density	0.017 kg/L	0.071 kg/L	0.68 kg/L	0.79 kg/L	0.77 kg/L	0.46 kg/L	0.83 kg/L
Toxicity	non toxic	non toxic	TWA 25 ppm	TWA 200 ppm	TWA 400 ppm	TWA 1,000 ppm	TWA 30 ppm
Flammability (% in air)	4 - 74%	4 - 74%	14.8 - 33.5	6.0 - 36.5%	1.2 - 6.7%	4 -15%	0.7 - 4.8%
Volumetric Lower Heating Value (LHV)(MJ/L)	2.43 - 6.8	8.52	12.7	15.7	5.76 - 8.5	22.2	35
Gravimetric LHV (MJ/kg)	120	120	18.6	19.9	7.48 - 11	48.6	43
Infrastructure read-iness for large scale de-ployment in mid-term H/M/L	L	L	H	H	M	H	H
Commercialisation status and pilot projects	Gen2 Energy and Global Energy Ventures developing compressed hydrogen shipping for short / mid-range routes	HySTRA- Hydrogen Energy Supply-chain Technology Research Association – Australia to Japan LH2 shipping	Bulk ammonia distribution and storage infrastructure is mature: 170 ships and 120 terminals worldwide	Methanol is a widely traded commodity with tankers up to 50,000 tonnes	Chiyoda, Mitsubishi and NYK shipped a bulk carrier cargo of MCH loaded with hydrogen from Brunei to Japan in 2020	Many commercial LNG production, distribution, storage and regasification assets worldwide	Refined products distribution and storage infrastruc-ture is mature

8. Separation of CO_2 and hydrogen using a pressure swing adsorption (PSA) unit
9. Recovery of the biogenic CO_2 as a valuable co-product
10. Recycling hydrogen from the SMR to the hydrogenation reactor.

Process flexibility and profitability

A unique feature of the PCH process is that it produces biomethane, biosyngas and hydrogen at various stages in the process. Biochar and biogenic CO_2 are also important co-products. According to the desired product mix, PCH can be designed to optimise production of any one, two or three of these energy gases in a ratio that is required by the system user.

Production of more than one bio-energy gas enables revenue diversification from the investment to reduce the commercial risk. During operation, some deviation from the design point can also swing the product mix towards market needs. This enables arbitrage to maximise production of the most profitable product(s) at any moment in time.

The biogenic CO_2 can either be sequestered, or liquefied and sold into the merchant CO_2 market for applications such as pH regulation in water, beverage carbonation and food freezing. The biochar can be monetised as a soil improver, and will also be eligible for carbon dioxide removal certificates since it permanently binds atmospheric carbon which the tree initially absorbed from the atmosphere into solid biochar.

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LNG CNG Fueling station France

Electrified reforming

In the PCH process, both the pyrolysis and the SMR stages require heat input to drive the chemical reactions.

The SMR requires heat input, and it also emits heat because the reformate gases are cooled between the WGS stage and the PSA unit. This heat can be recovered and used to drive the pyrolysis reaction. This process integration maximises the energy efficiency of PCH.

Classical SMRs use a flame box to heat up multiple tubes filled with reforming catalyst, through which the methane and steam flow. The flame is generally fired with additional methane combined with tail gases from the downstream PSA unit.

In the case of PCH, biomethane produced in the catalytic hydrogenation reactor, or natural gas, can be used. On the other hand, the SMR can be electrically heated. Electrical heating of the SMR with renewable power, such as that from hydro, wind and solar resources, simultaneously reduces the carbon intensity of the biomethane and maximises the biomethane yield.

Electrified reforming and electrically heated SMRs are being developed by Topsøe with their eREACT™ system and Sypox. In a classical flame-heated SMR approximately one third of the methane feed is to the burner. Therefore, if this energy input is replaced by renewable electricity the CO_2 intensity of the products from the SMR can be reduced by 30%.

Carbon-negative energy gases

When the overall carbon balance of the PCH process is considered, the biomethane is produced with a negative carbon intensity. Meaning, that its production has resulted in the removal of carbon dioxide from the carbon cycle.

According to the economic requirements of a project, the revenues from one product can be used to partially offset the costs of producing another product. Thus, biomethane can be sold at a price which is less than the cost of natural gas as a fossil fuel.

There are very few renewable energy processes that can achieve fossil fuel cost parity: PCH is one of them. Beyond that, there are very few carbon-negative pathways to produce transportable energy vectors such as bio-hydrogen, bio-syngas or biomethane. PCH is able to achieve all three.

Secret sauce

Research into the catalytic conversion of un-cleaned pygas has taken place over many years. Until now, this direct conversion of un-cleaned pygas has been held back by the propensity of tars in the pygas to coke onto the catalyst, which generally uses a nickel-based compound as the active material.

In the PCH process, conversion of pygas to biomethane is achieved in the catalytic hydrogenation reactor. There are two critical differences that this concept introduces which overcome problems from past attempts to directly process pygas. Firstly, hydrogen is introduced into the reactor. Secondly, the reactor design itself is proprietary to G4 Insights.

The secret sauce built into the G4 Insights technology is the internal design of the hydrogenation reactor. It carefully controls the strong exotherm to avoid catalyst damage. Simultaneously, it achieves an exceptionally high conversion of tars and other chemicals in the pygas to methane through tight control of the temperature profile in this reactor.

2,000 hours of testing in Canada have proven the validity of the PCH process and the robustness of the hydrogenation reactor. G4 Insights has gained sufficient operational data to model the catalyst performance.

As with almost all catalytic processes, catalyst replacement at periodic intervals is required. In the case of PCH, the catalyst loading and replacement is a very small incremental cost, because the main active ingredient is nickel, not a precious metal such as platinum, palladium or ruthenium. gw