Arthur D Little

Bio Methane based Chemicals

Bio Gas as a feedstock for Chemical Manufacture

Interim Presentation to
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The objective of this report is to provide a first assessment of the market potential and economic viability of Bio Gas as a feedstock for chemical manufacture

Bio Gas

- Bio gas is gas produced from the anaerobic digestion of organic matter, e.g.:
  - Animal manure, sewage, Municipal Solid Waste
- Composition of Bio Gas varies depending on the origin of the anaerobic digestion process
- After it is processed to required standards of purity, Bio Methane becomes a renewable substitute for natural gas

Compound	Chem	%
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-50
Nitrogen	N_2	0-10
Hydrogen	H_2	0-1
Hydrogen sulphide	H_2S	0-3
Oxygen	O_2	0-2

Bio Gas as Chemical Feedstock

- The chemical industry uses significant quantities of natural gas both as fuel and feedstock
- Bio Methane could replace natural gas as feedstock to produce “green” bio-based chemicals
- No additional infrastructure investments are required – Upgraded Bio Gas can be injected directly into existing natural gas distribution networks
  - In the Netherlands, Bio Gas is currently being injected into the distribution network at 5 locations

Objective

- Evaluate the potential for use of Bio Gas as a feedstock for chemical manufacture
  - Market overview: current usage of natural gas as a chemical feedstock
  - Using Biogas as a feedstock for chemicals manufacture

Source: Arthur D. Little analysis

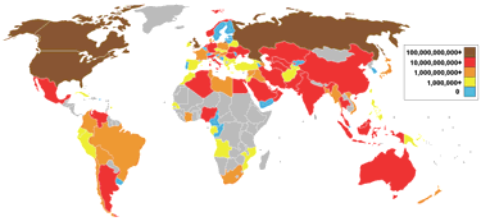
1 Market overview: current usage of natural gas as a chemical feedstock

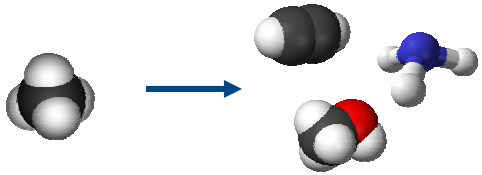
Natural gas for chemical feedstock is mostly used to produce fertilizers (via Ammonia) and Methanol, Oxo chemicals and Acetylene are other key derivatives

Europe

C1 Chemical Value chain – Overview

Methane (natural gas) → **Methane derivatives** → **End markets and products**





- Methane is the major component of natural gas (typically 85-96% by volume)
- Only a small share of European natural gas is used for the chemical feedstock (~3%)

- Main chemical derivatives are:
  - Ammonia
  - Methanol
  - Oxo chemicals
  - Acetylene
  - Hydrogen cyanide
  - Carbon disulfide

- For the agricultural industry natural gas is transformed to fertilizers (via ammonia)
- Chemical industry uses natural gas for e.g. resins, plastics, solvents and as intermediates

Source: SRI, Arthur D. Little analysis

Natural gas based chemical products serve a diverse set of end markets

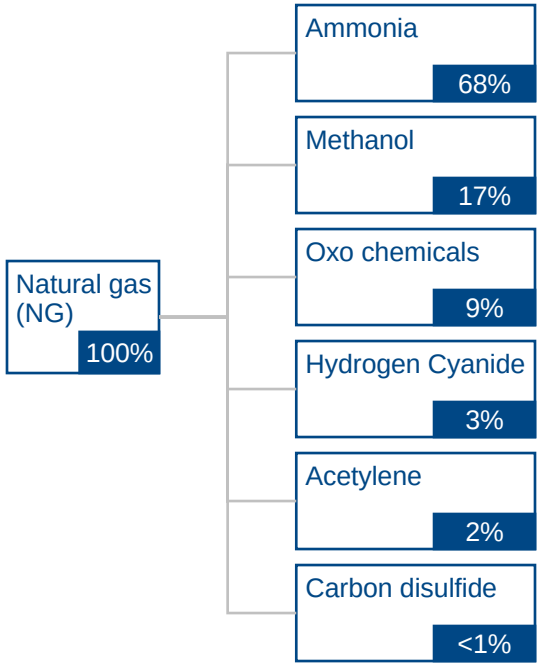
C1 Chemical Value chain – Detail

Feedstock	*1st line derivatives*	*End Products*		*Key End markets*
Natural gas	Ammonia	– Fertilizers – Adhesive raw materials (glue, resins, foam) – Animal nutrition	– Refrigeration – Synthetic tanning agents – Dyes, pigments, coatings – Crop protection	– Agriculture industry - ~90% of ammonium is used for fertilizers in WE[1)] – Animal feed industry – Chemical industry (resins, coatings, refrigeration, fibers)
	Methanol	– Resins, plastics – Solvents (e.g. Anti-scaling agents) – Fuel (incl. octane)	– Antifreeze – Crop protection – Vitamins – Acidity regulator (E260)	– Chemical industry - ~50% of methanol is used for resins/plastics (formaldehyde) in WE – Chemical industry – 5-10% of methanol is used for production of PET bottles (acetic acid) in WE – Food industry (acetic acid), Agriculture, …
	Oxo chemicals	– Solvents – Plastics, resins	– Coatings – Lubricants	– Chemical industry – most Oxo chemicals are used to produce plastics, resins etc.
	Acetylene	– Solvents – Fuel – Cosmetics, pharmaceutical, animal nutrition, plastics, vitamins, …		– Chemical industry – most acetylene is used in chemical syntheses (plastics, elastic fibers, polyurethanes)
	Hydrogen Cyanide	– precursor to sodium cyanide and potassium cyanide (used mainly in mining)		– Mining, chemical industry (intermediate for e.g. Acetone Cyanohydrin)
	Carbon disulfide	– crop protection, bleaching agents		– Chemical industry (intermediate)

1) Western Europe
Source: SRI, Arthur D. Little analysis

Usage of natural gas as chemical feedstock is about 7 bn m^3 in Western Europe – Most natural gas is used for production of Ammonia

Breakdown of NG based chemical production (Western Europe)



Market Segmentation	Production capacity[1] (million metric tons)	Stoichiometric conversion factor (m^3/metric tons)	Total NG consumption[2] (bn m^3)
Ammonia 68%	19.7	506	4.7
Methanol 17%	3.7	358	1.2
Oxo chemicals 9%	3.8	181	0.6
Hydrogen Cyanide 3%	0.5	424	0.2
Acetylene 2%	0.2[3]	880	0.2
Carbon disulfide <1%	0.2	150	<0.1 +
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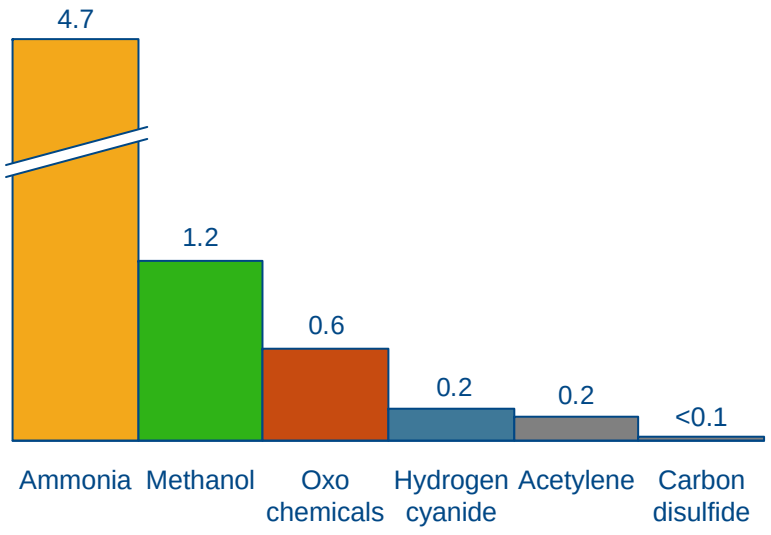
1) Not corrected for capacity utilization
2) Corrected for capacity utilization – see slide xxx for details
3) Estimate – only Natural gas feedstock
Source: SRI, CEH, Arthur D. Little analysis

Germany uses most natural gas as chemical feedstock, followed by Netherlands, France and United Kingdom

Indicative

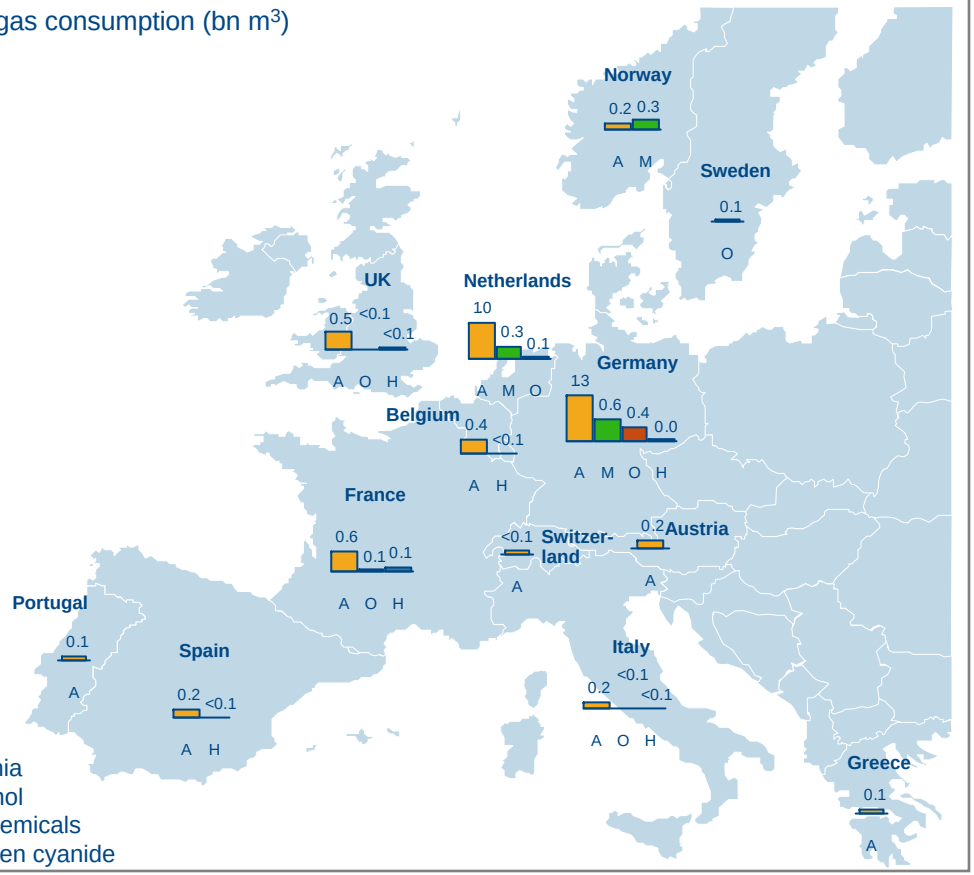
Western European consumption of natural gas for chemical industry

Natural gas consumption (bn m³)



Consumption of main derivatives per country (bn m³)

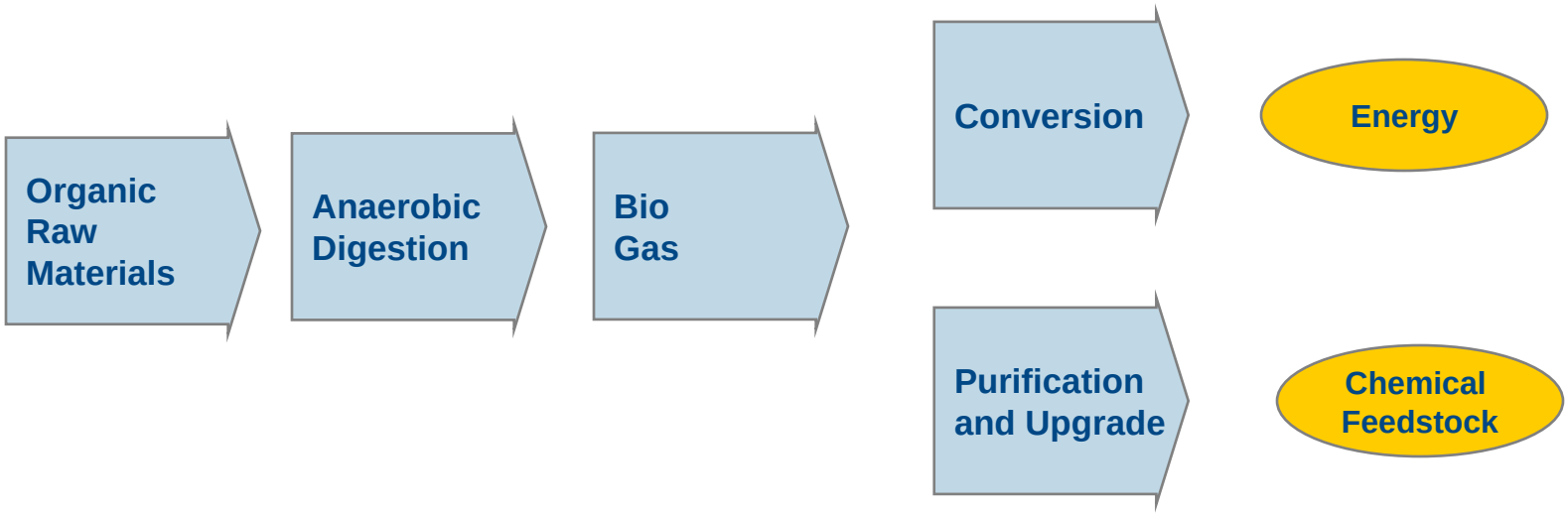
Natural gas consumption (bn m³)



Source: SRI, CEH, Arthur D. Little analysis

Biogas is produced via digestion or thermal gasification – Sewage sludge, household/ industrial/agricultural waste and crops are the main feedstock for producing Bio Gas

- Bio gas is gas produced through an anaerobic process where bacteria convert biodegradable organic matter into methane and CO_2
- Possible feedstock for this process are: sewage sludge, household, industrial and agricultural waste
- To be injected into the gas distribution network and used as a chemical feedstock, Bio Gas requires upgrading to a high level of methane concentration – Bio Methane
- As the chemical producer purchases certificates but will not use the Bio Methane stream directly, changes to the chemical production process will not be required



Source: Biogasmax (EU), Austrian Bio Energy centre, Arthur D. Little analysis

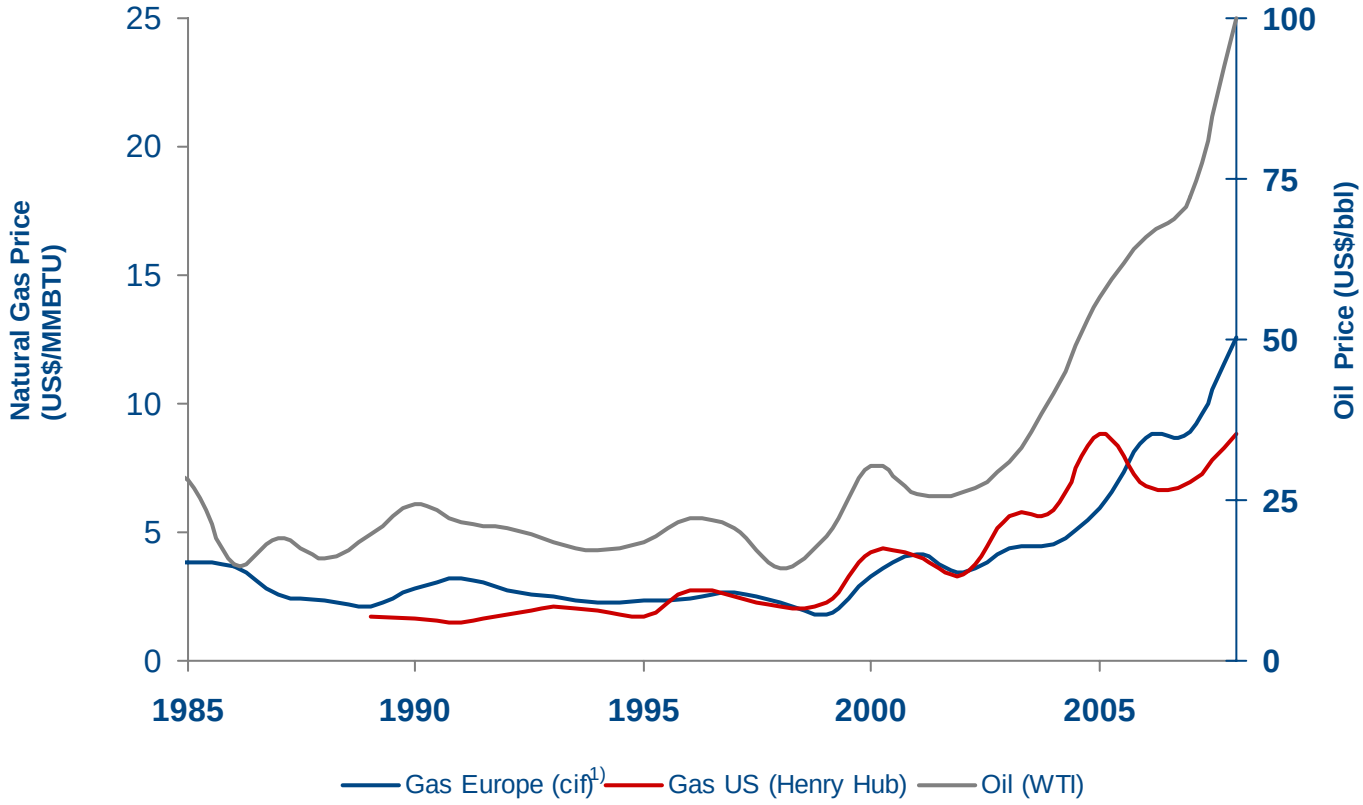
Biogas is typically significantly more expensive than Natural Gas and would imply a significant price premium for first line C1 derivatives

- Natural gas prices are highly volatile and had been trending up until 2009, in line with oil price movements
- Bio Gas cost price is less volatile and depends primarily on:
  - Price of the bio feedstock
  - Size of the Bio Gas generation installation
  - The level and means of upgrading required before re-injection
- With present technology and feedstock prices cost of Bio Gas will be around 70 € ct/Nm3
- After accounting for Government subsidies, the incremental cost of using Bio Methane ranges from 20-35 ct/Nm3, depending on the price of Natural Gas
- Switching to Bio Gas would imply a significant product premium for first line Methane derivatives
- There are several other feedstocks for producing “green” C1 based products, the economics of those relative to Bio Gas should be a topic of further study:
  - Biomethanol from glycerine, a sidestream of biodiesel production
  - Syngas directly from biomass gassification
  - CO based chemistry from the reduction of CO_2

Source: Arthur D. Little analysis

Natural gas prices are highly volatile and had been trending up until 2009, in line with oil price movements

Natural Gas Pricing, Europe & US (1984 to 2008)

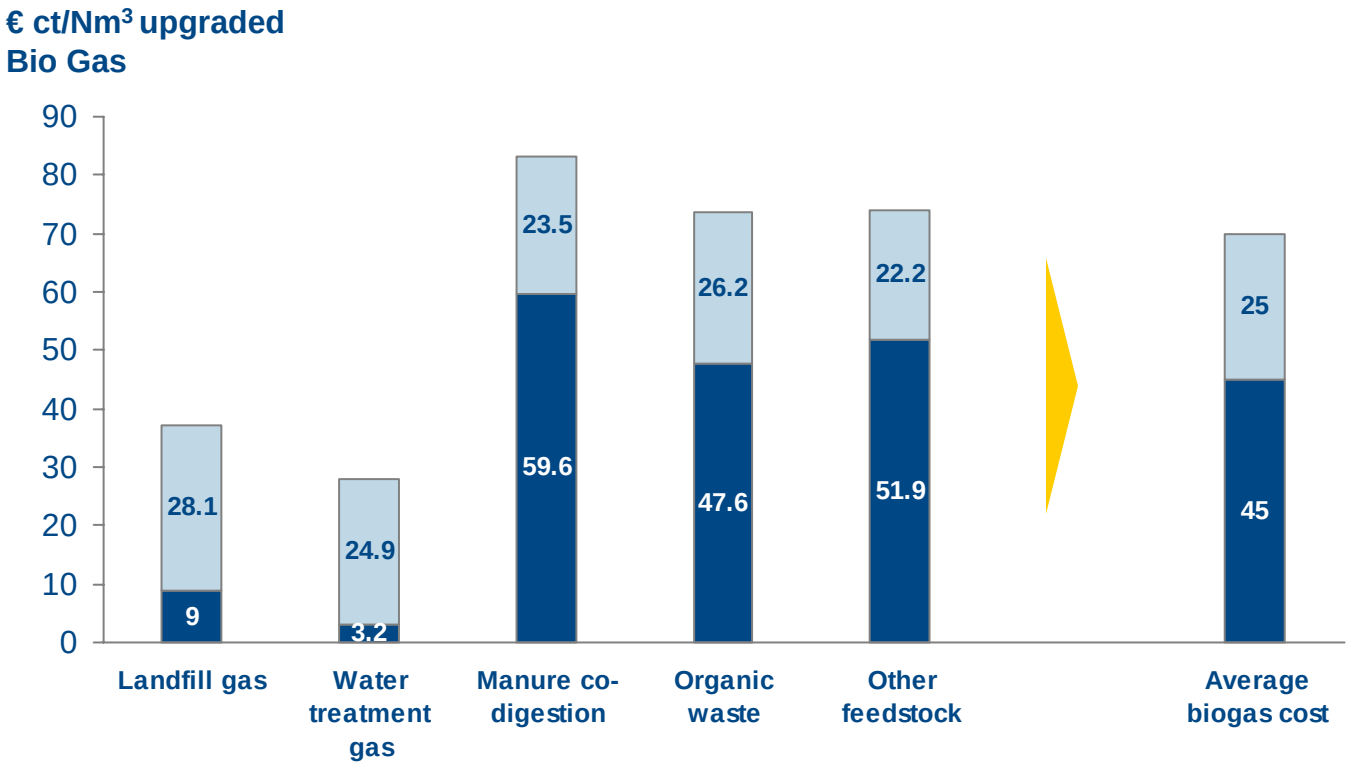


Source: BP Statistical Review of World Energy, Arthur D. Little analysis 1) cif = cost, insurance & freight

With present technology and feedstock prices cost of Bio Gas will be around 70 € ct/Nm3

Estimates

Bio Gas production and upgrading cost



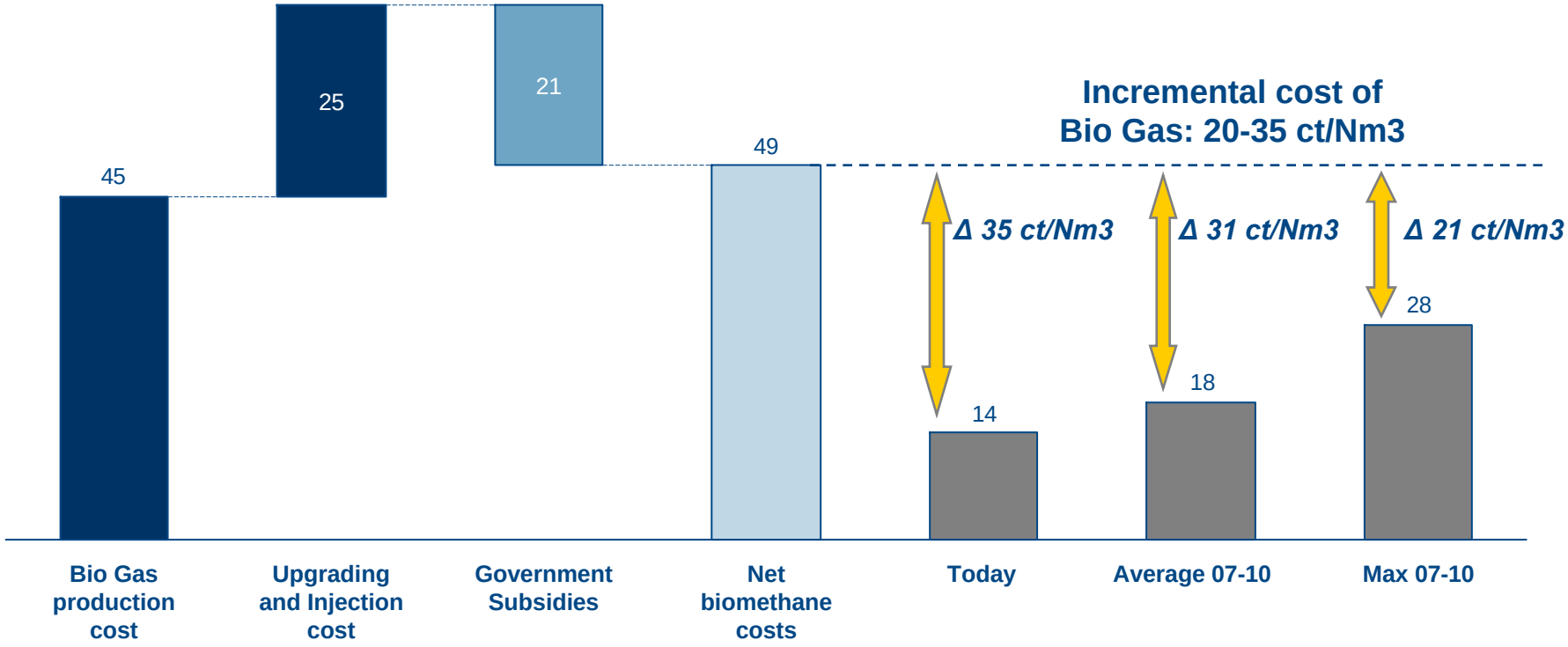
- Most landfill gas and sewage gas currently produced is used for electricity generation on site
  - Economics of switching to upgrading and injection as Bio Methane are not attractive
- Incremental Bio Gas from landfills and water treatment facilities is unlikely
  - Few new landfills being added as landfilling is discouraged
  - There is overcapacity in water treatment today
- Incremental Bio Gas for chemical use will have to come from other feedstockss

Source: ECN/KEMA

After accounting for Government subsidies, the incremental cost of using Bio Gas will range from 20-35 ct/Nm3, depending on the price of Natural Gas

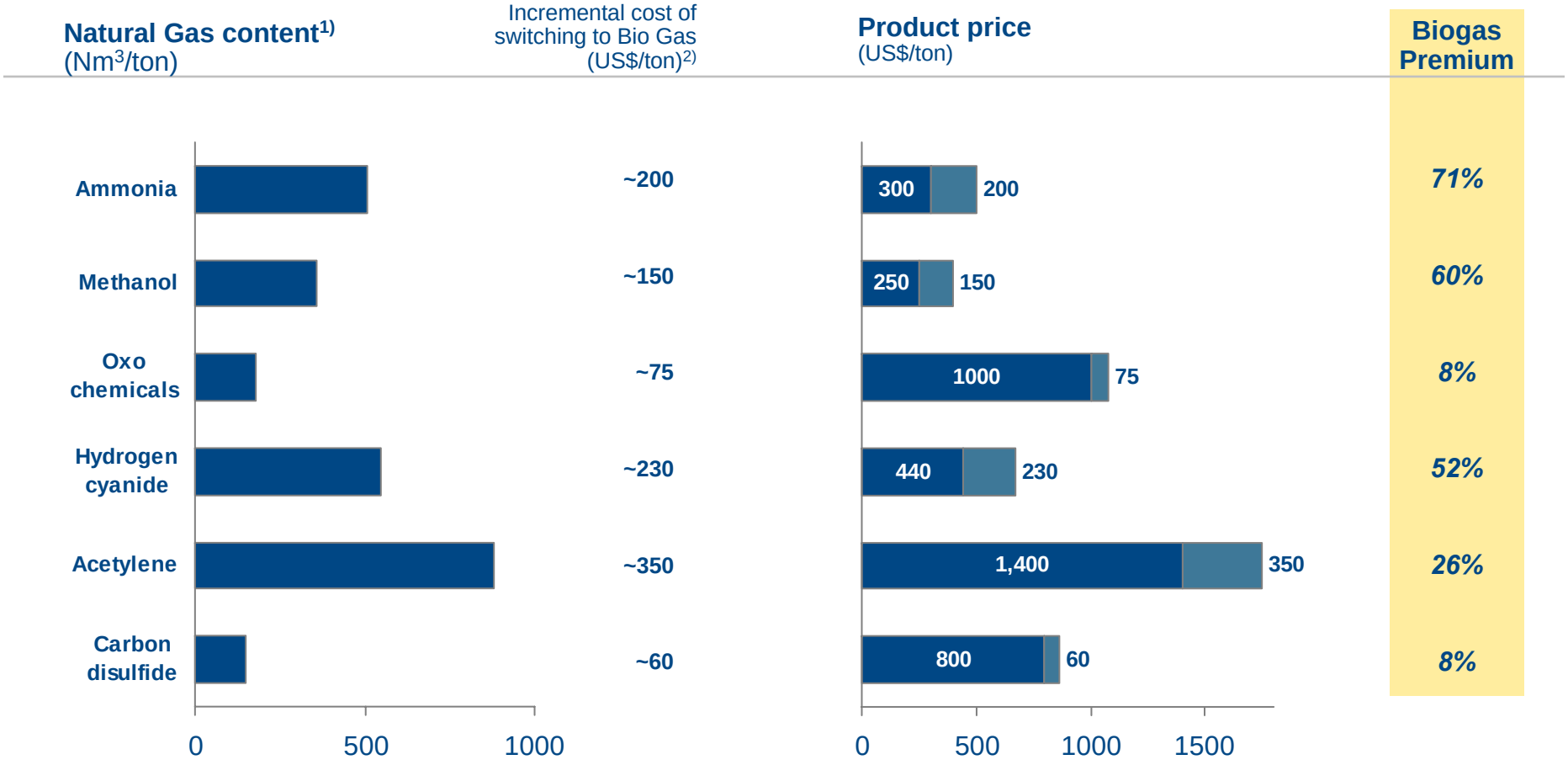
Estimates

Incremental Cost of Producing Bio Gas (€ ct/Nm3)



Source: APX, Arthur D. Little Analysis 1) Biogas production subsidized in many European countries (Dutch 2010 Bio Gas producer subsidy applied, 20.8 €ct/nM3)

Switching to Bio Gas would imply a 10-70% product premium for first line Methane derivatives

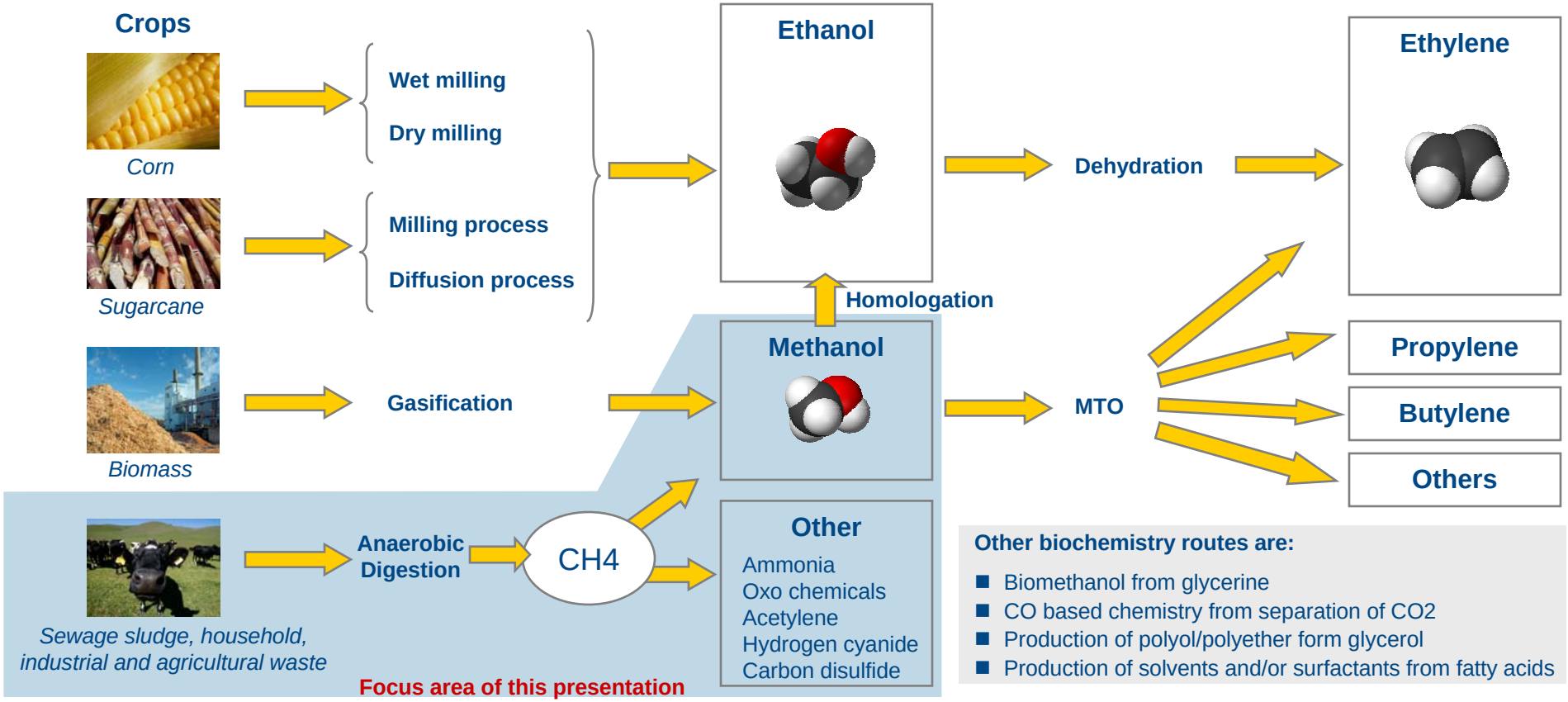


Source: Arthur D. Little analysis

Other biochemical routes should also be considered in understanding and evaluating the potential impact of bio methane based chemistry

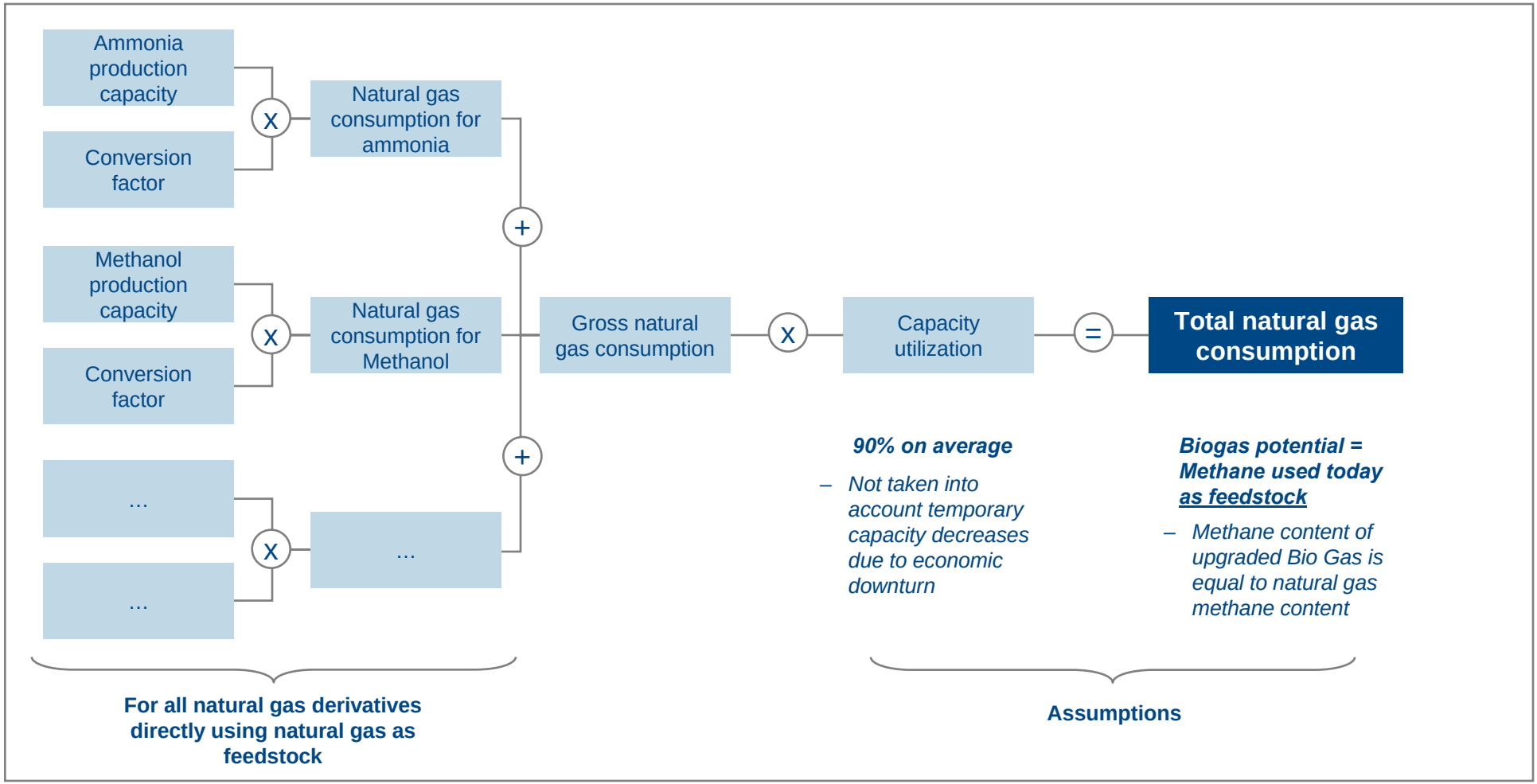
Not Exhaustive

Overview of biochemistry routes



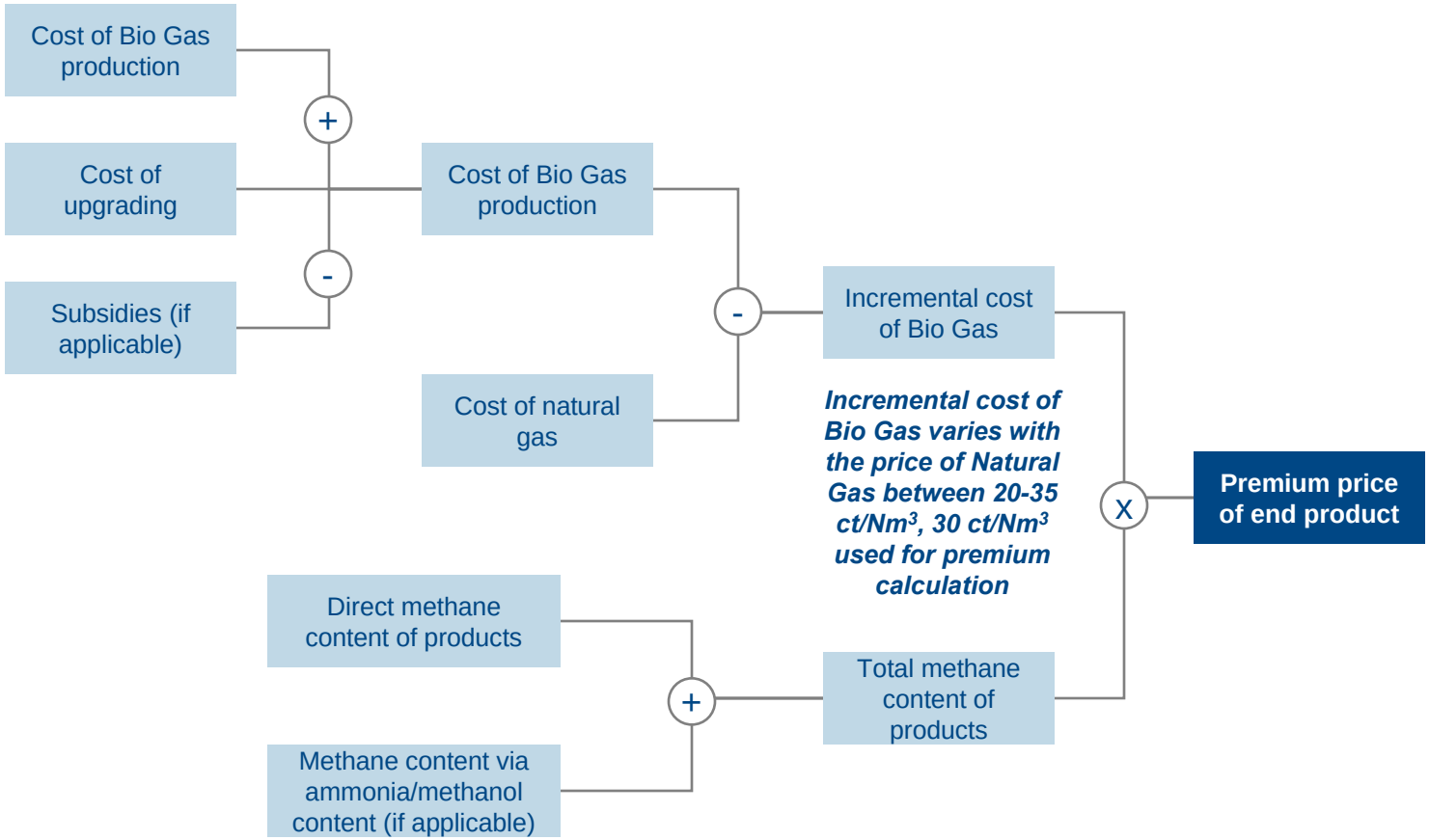
Source: Arthur D. Little analysis, corporate websites

Methodology and assumptions for calculating natural gas consumption (Bio Gas market potential)



1) Assuming capacity utilization in West Europe of 90%
Source: Arthur D. Little analysis

Methodology and assumptions for calculating Bio Gas premium



Source: Arthur D. Little analysis