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Optimal decarbonisation trajectories for the global (petro)chemical sector

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Rationale

World

2013

Million tonnes of oil equivalent

INDUSTRY	**2623.45**
Iron and steel	473.90
Chemical and petrochemical	366.99
Non-ferrous metals	118.87
Non-metallic minerals	361.67

NON-ENERGY USE	**798.77**
in industry/transf./energy	769.96
of which: chem./petrochem.	*577.14*
in transport	12.22
in other	16.60

Energy consumption

10% of total global final energy

27% of industrial final energy

Challenging sector to decarbonize

Source: IEA (2016) *World Energy Balances.*

Greenhouse gas emissions

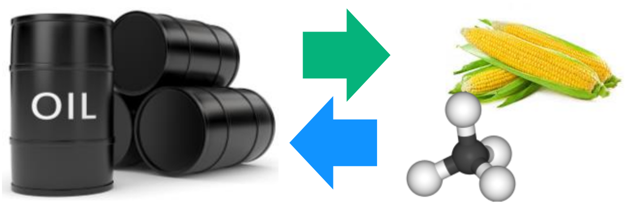
7% of anthropogenic GHG emissions

20% of industrial GHG emissions

Many more upon *latent release*

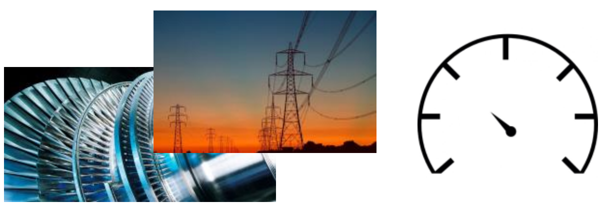
Source: IEA, DECHEMA & ICCA (2013) *Technology Roadmap: Energy and GHG Reductions in the Chemical Industry via Catalytic Processes*

Current prescriptions for mitigation



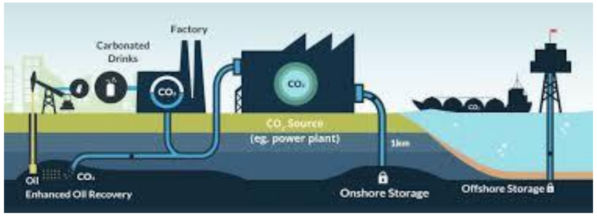
Fuel and feedstock switching

- Non-biomass benefits 'capped'
- Biomass sustainability challenges
- IPCC total in 2050 ~ 100-500 EJ yr^{-1}
- Economic feedstock ~ 15-17 EJ yr^{-1}



Process energy efficiency

- No direct impact on feedstock
- Process energy proportion is declining as a share of the sector's total energy inputs



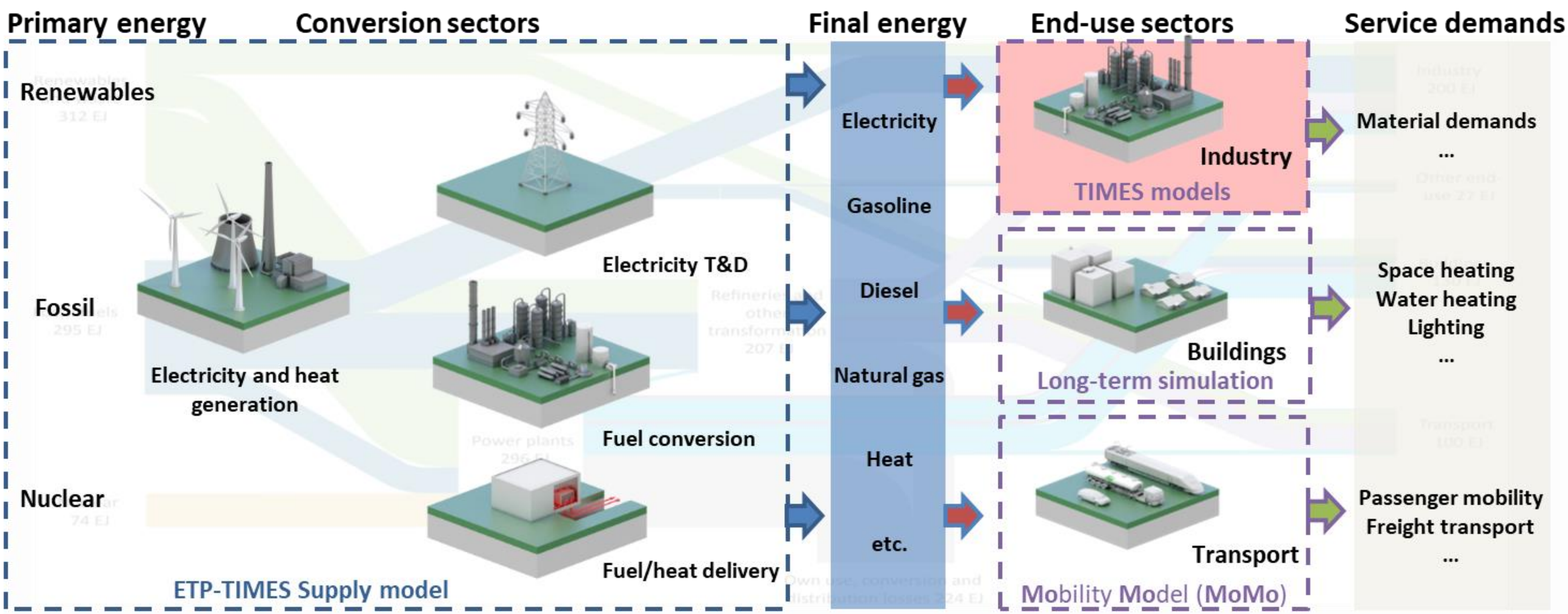
Innovative low carbon processes (incl. CCS)

- Innovation required in advance!
- Scaling and commercial difficulties
- 150 $MtCO_2$ yr^{-1} in chemical sector by 2025
- Current global *capacity* 44 $MtCO_2$ yr^{-1}

Too many studies to list; some notable academic authors:

Martin Patel
Martin Weiss
Maarten Neelis
Dolf Gielen
Ernst Worrell
Kornelis Blok
Deger Saygin
Vassilis Daioglou

The IEA's ETP modeling fleet



- Four soft-linked models based on simulation and optimisation modelling methodologies
- Model horizon: 2014-2060 in 5 year periods
- World divided in 28-42 model regions/countries depending on sector
- For power sector linkage with dispatch model for selected regions to analyse electricity system flexibility

Chemicals model structure overview

Simplified, but substantial coverage…
- *~73% overall energy coverage*
- *~ 55% process energy coverage*
- *~ 98% feedstock energy coverage*

Technology parameters

- Process energy
- Feedstocks
- CAPEX/OPEX
- Capacities
- Fuel costs

Process emissions

Energy-related emissions

TIMES model of the chemical and petrochemical sector

- Production technologies
- Capture technologies
- Ancillary technologies (e.g. utilities)

- Ethylene
- Propylene
- BTX aromatics
- Ammonia
- Methanol

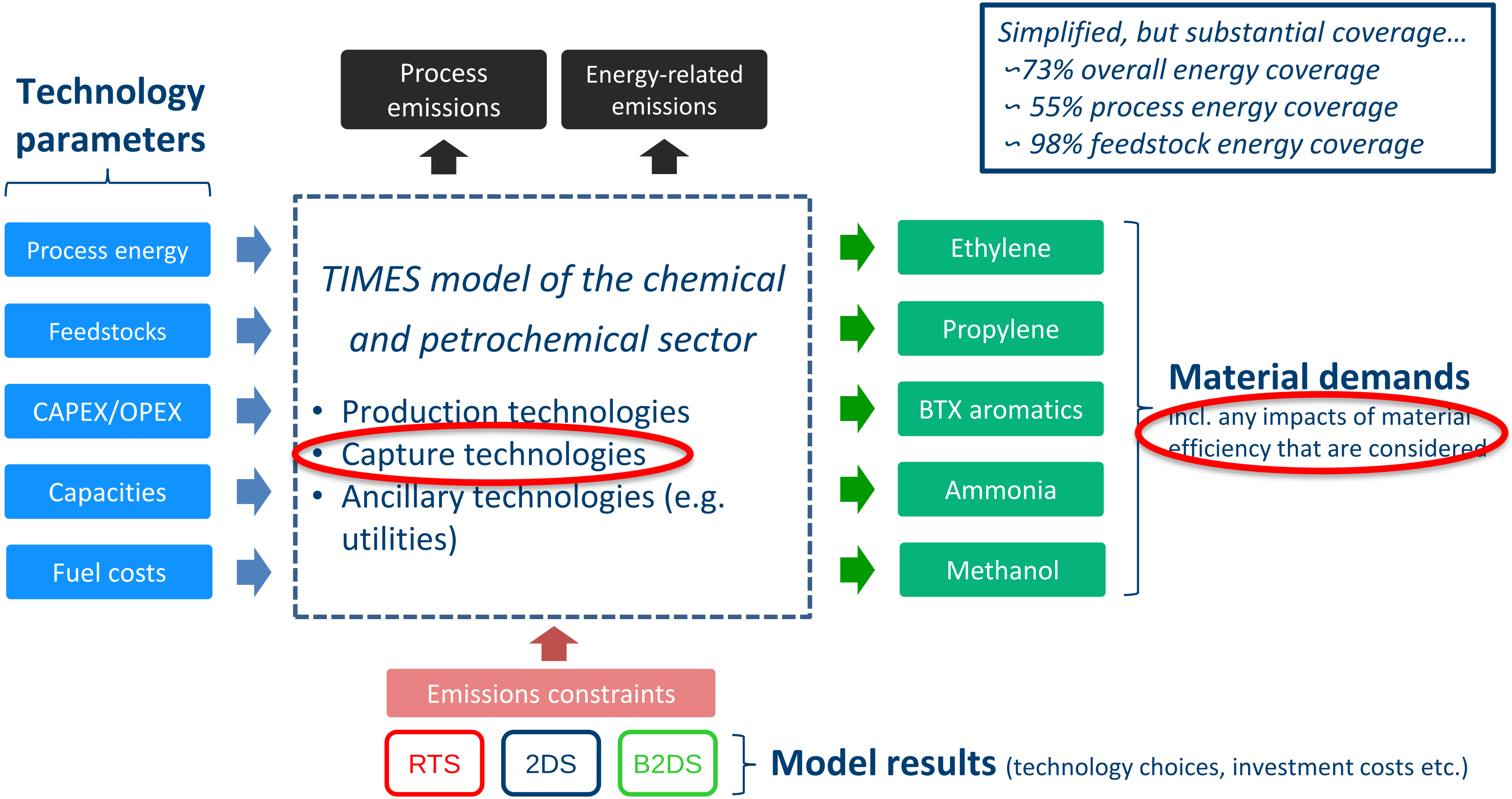
Material demands
incl. any impacts of material efficiency that are considered

Emissions constraints

RTS | 2DS | B2DS

Model results (technology choices, investment costs etc.)

Chemicals model structure overview



Carbon capture and utilisation

Indicative schematic of capture/utilisation routes

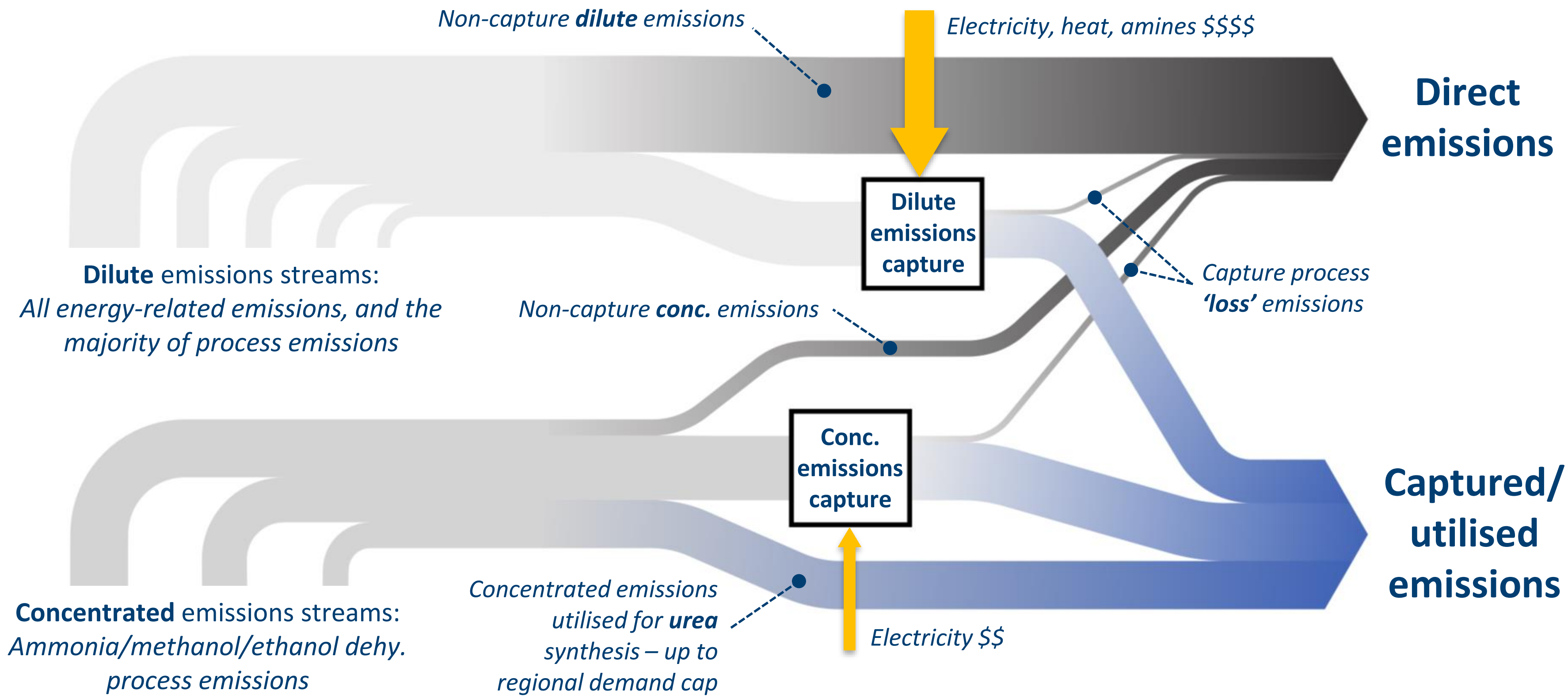
*Line weights **not to scale***

Dilute emissions

Concentrated emissions

Captured/utilised emissions

Direct emissions



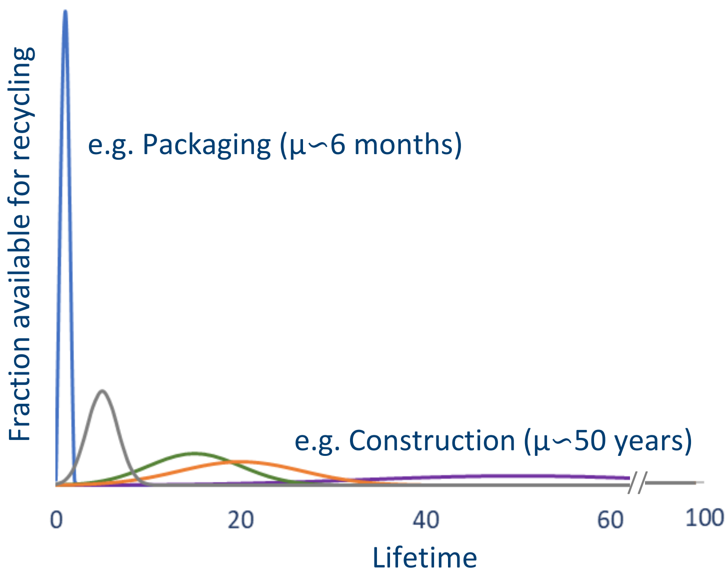
Material efficiency (thermoplastic recycling)

For each **resin**, **region** and **time slice**…

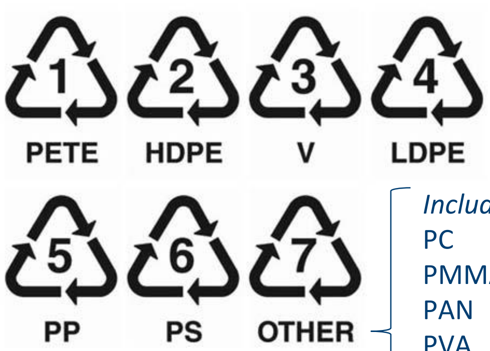
$$\textit{Primary chemical savings} \sim f\,(\,\eta_d, \eta_y, \eta_c, Q_p, \mathbf{C}\,)$$

Where; η_d = 'down-cycling' factor (%), η_y = recycling yield (%), η_c = collection rate (%), Q_p = recyclable plastic (Mt), **C** = mapping matrix.

How much recyclable plastic is available?

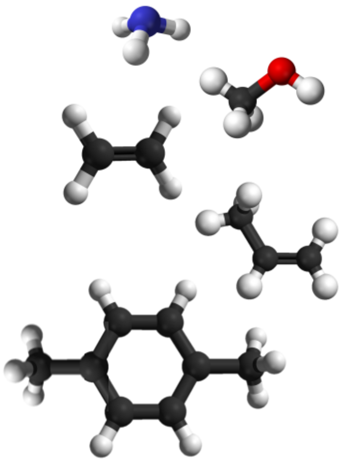


What is its composition?



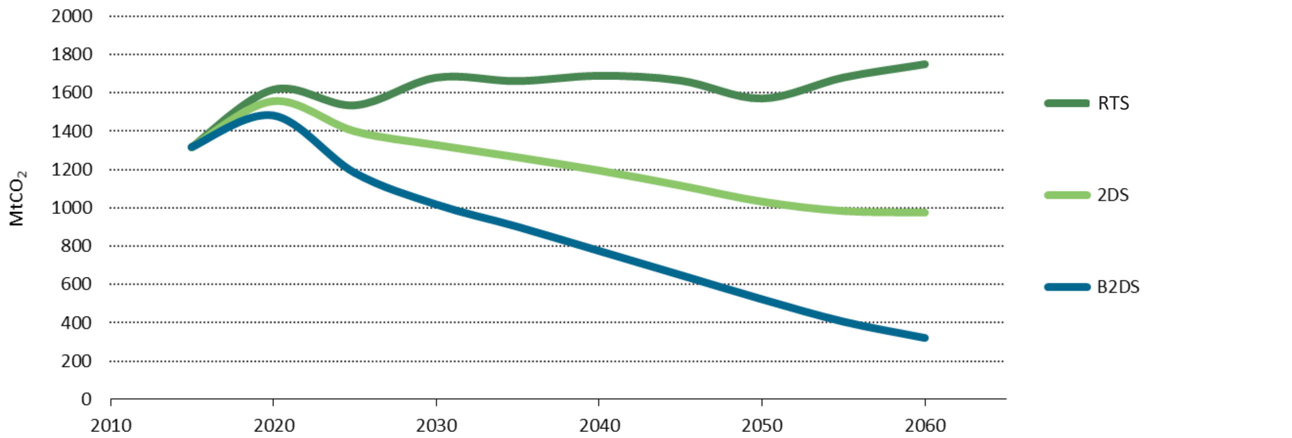
Included:
PC
PMMA
PAN
PVA
ABS
SAN

Primary chemical savings?

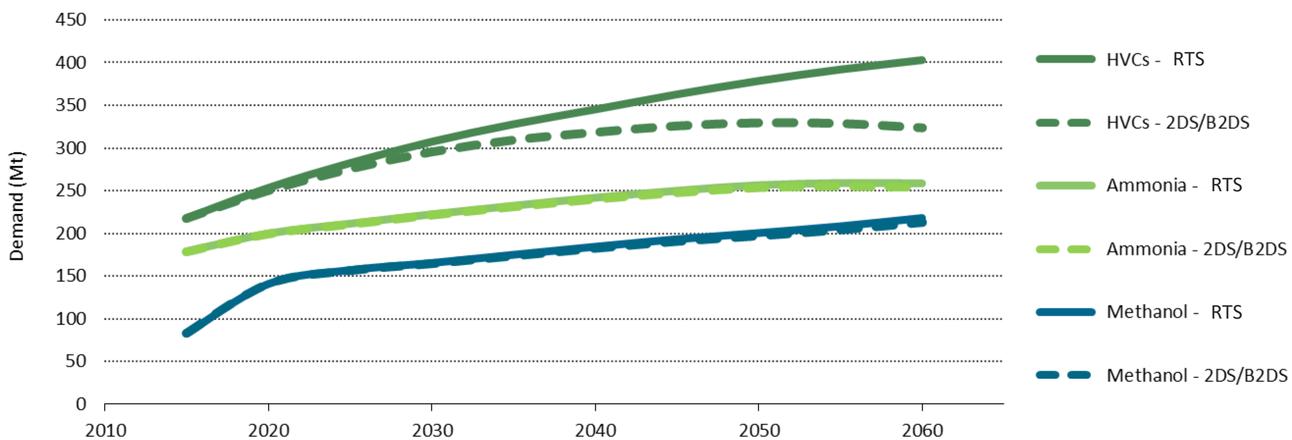


Scenarios and demand (global)

Direct emissions



Primary chemical demands



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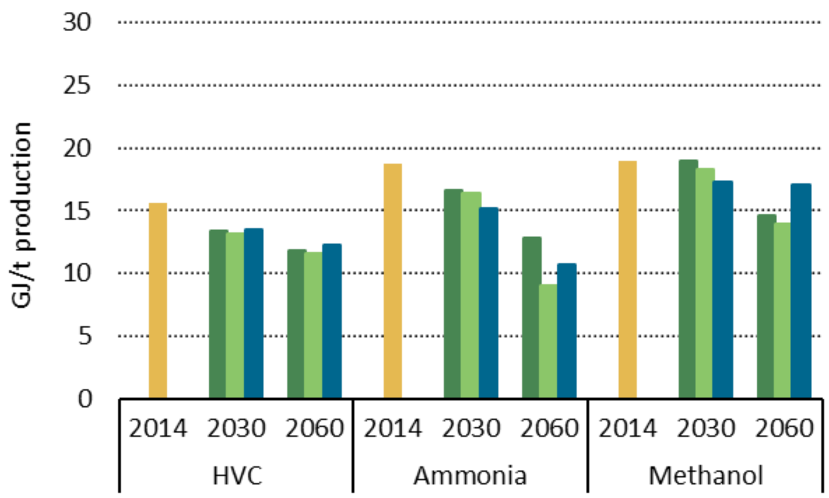
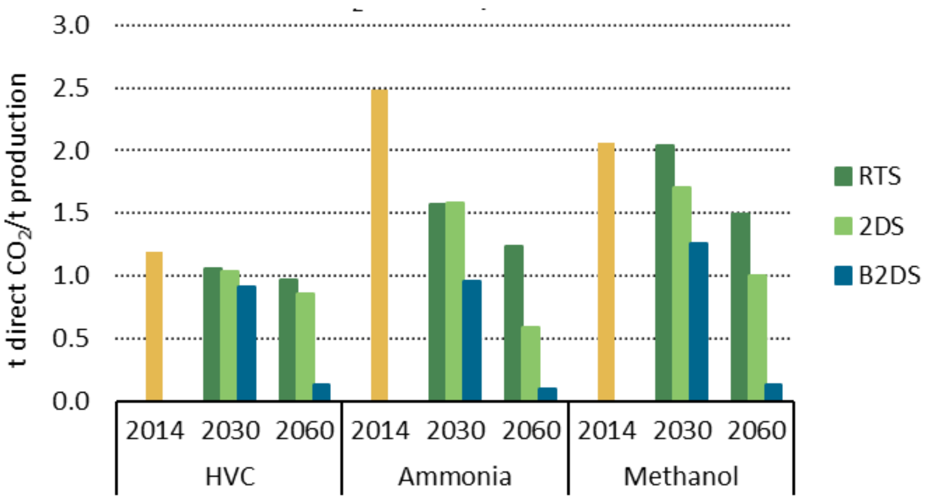
Results: Product-focused overview

Energy intensities (LHS graph) and direct CO_2 intensities (RHS graph) for each chemical/scenario

- B2DS energy intensities higher than 2DS in 2060 – low-carbon routes and capture
- Virtually complete decarbonization (~90% per unit of output) is required in the B2DS by 2060
- Significant emissions cuts needed early (24-62% per unit by 2030) to avoid greater expense

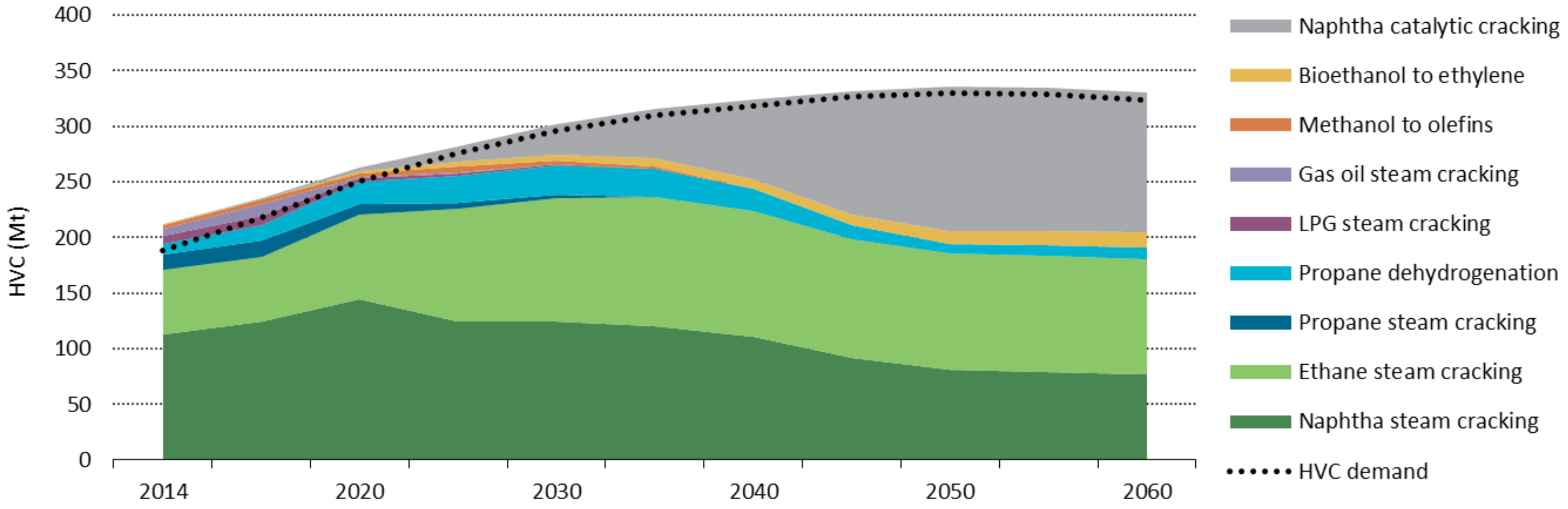




B2DS results

HVC production – penetration of various technologies throughout horizon

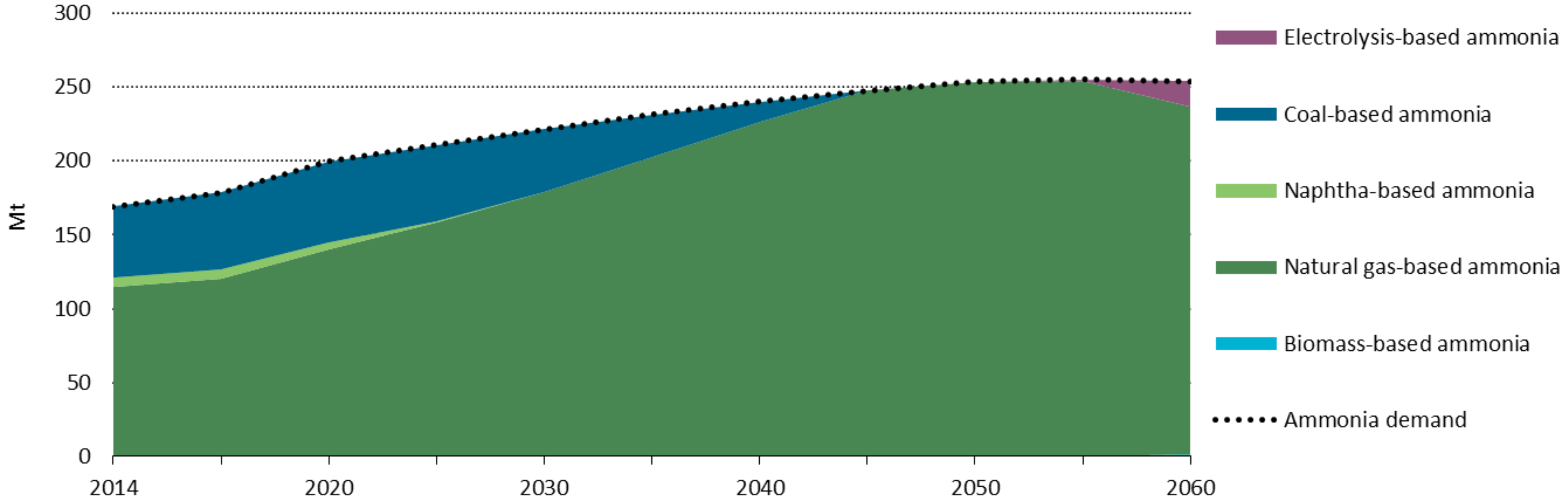
- Traditional steam cracking routes remain important in 2060
- On-purpose technologies' importance diminishes in the long-term



B2DS results

Ammonia production – penetration of various technologies throughout horizon

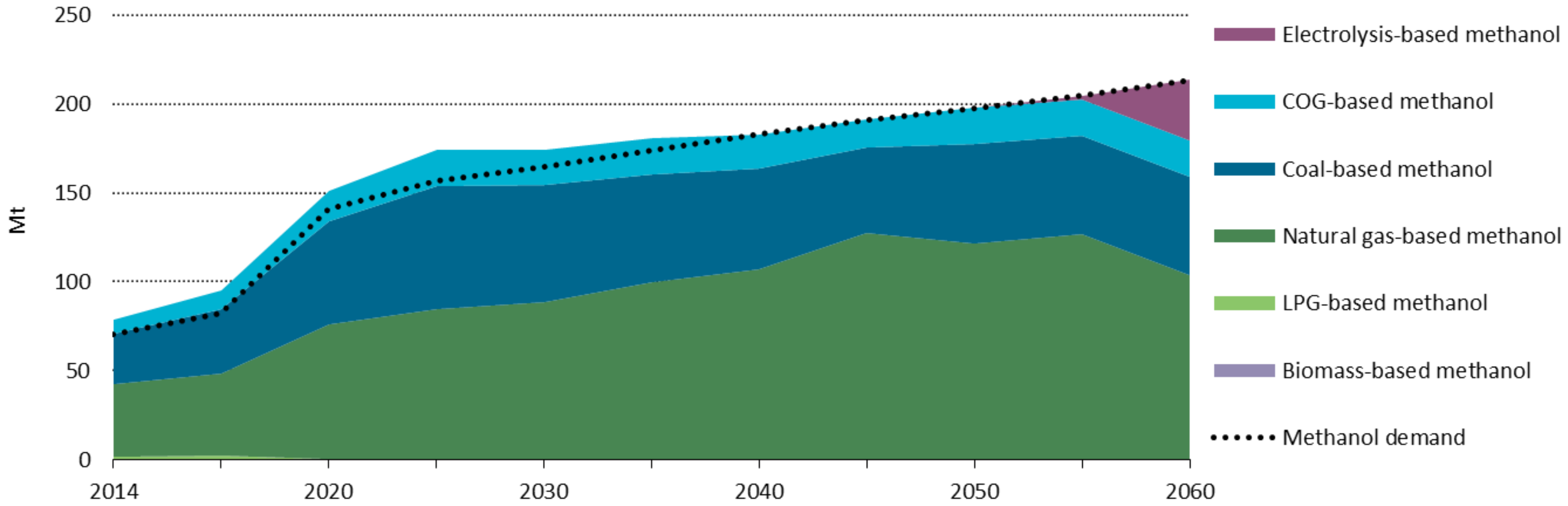
- Intuitively, coal-based ammonia (even with CO_2 capture/utilisation) is phased out by 2045
- Renewable hydrogen route only appears attractive after 2055



B2DS results

Methanol production – penetration of various technologies throughout horizon

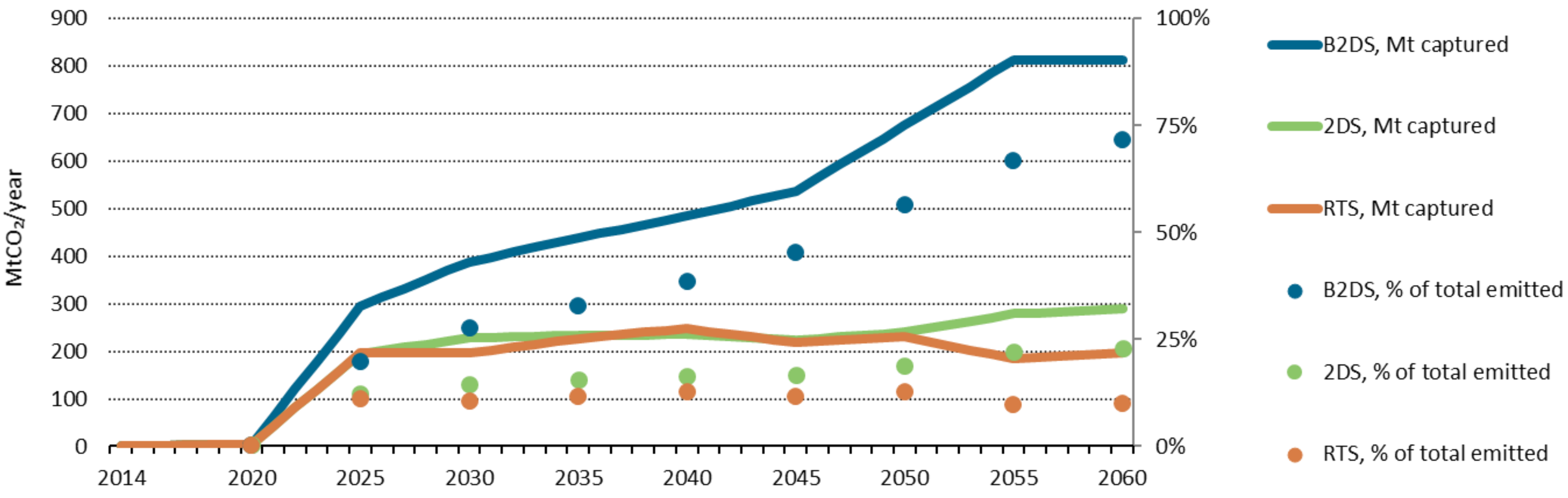
- Similar to ammonia; renewable hydrogen route competitive after 2055
- Otherwise feedstock mix remains nearly unchanged in 2060, albeit with CO_2 capture



Summary of CO_2 capture results

CO_2 capture – total penetration in each scenario throughout horizon

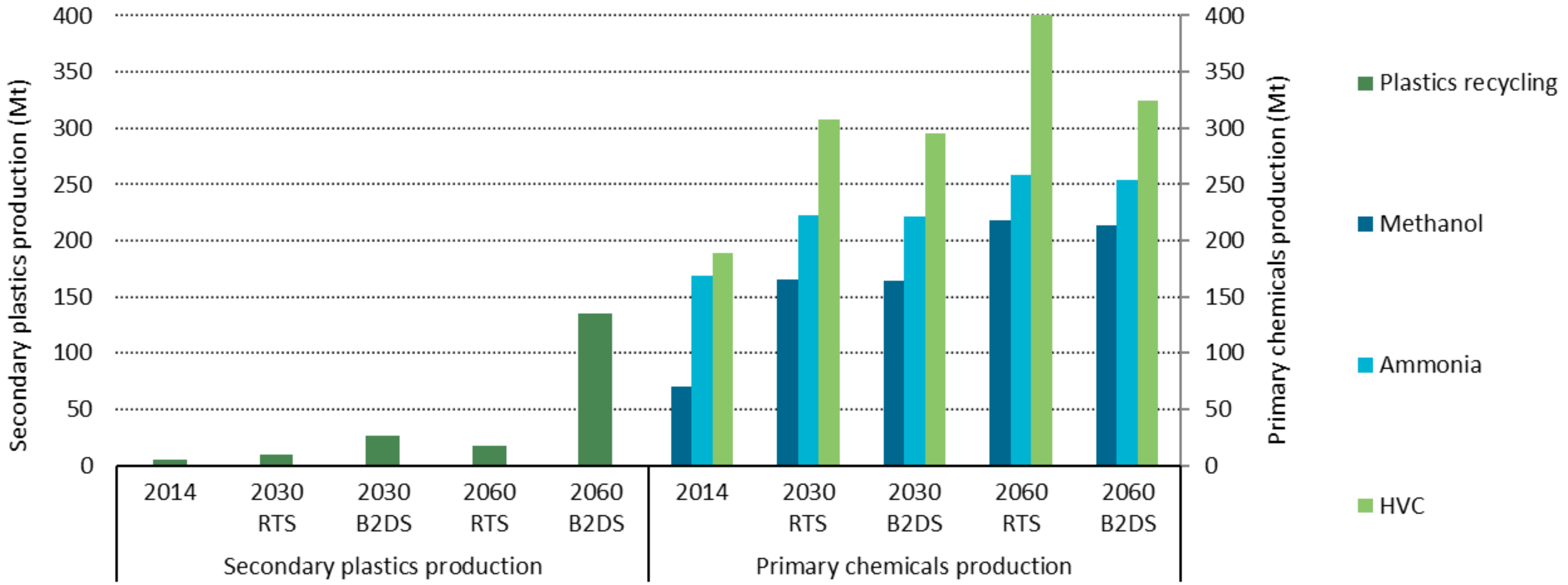
- 2DS requirements do not diverge significantly from RTS until after 2040
- Much progress is needed – current global *capacity* for all applications is roughly 44 $MtCO_2$

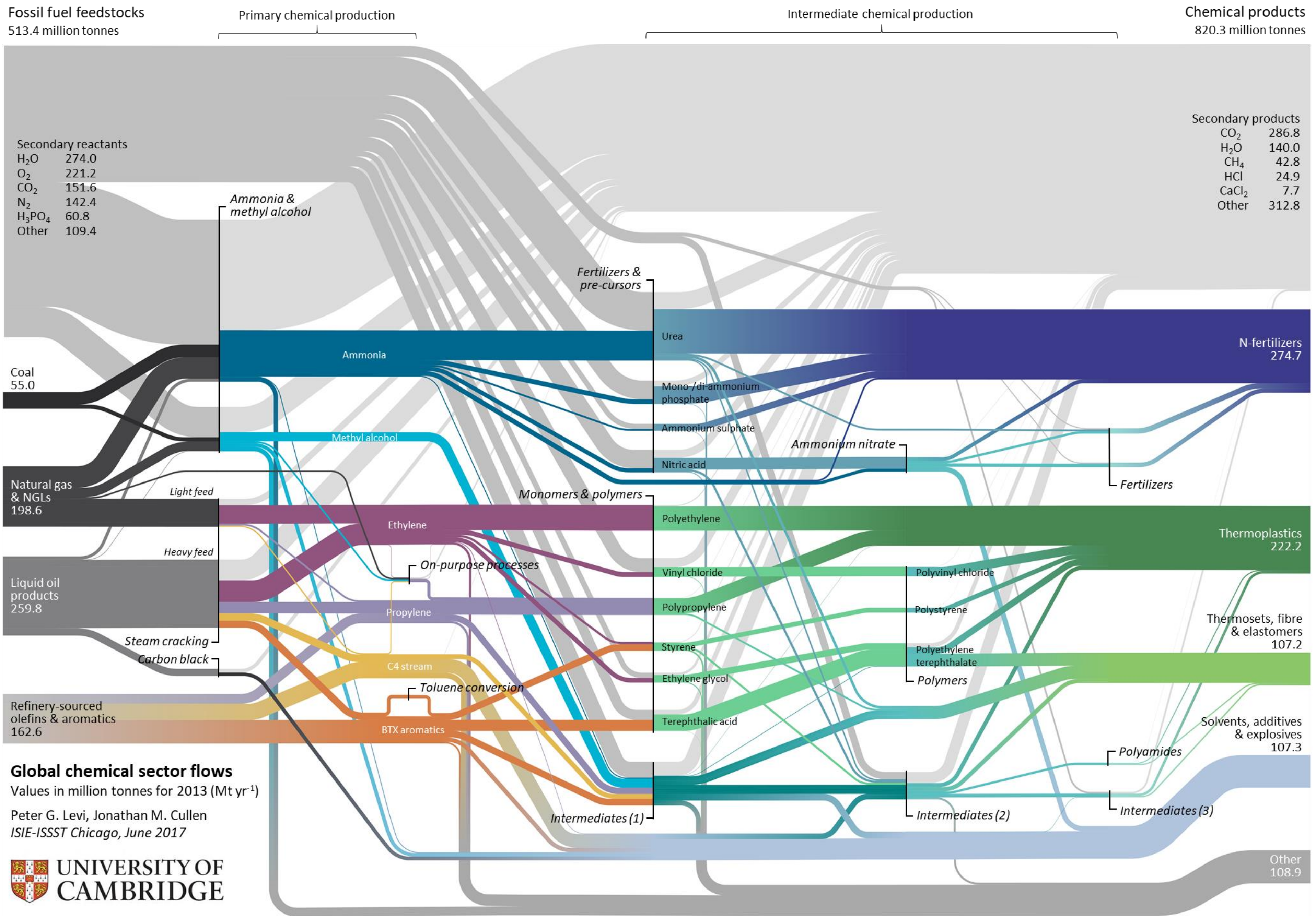


Summary of material efficiency savings

Material efficiency – secondary plastics production/subsequent primary chemicals demand

- Majority of impact on HVCs as pre-cursor monomers are principally olefins and aromatics
- More than a fifth of thermoplastic demand is met by secondary routes in 2060




Fossil fuel feedstocks
513.4 million tonnes
Primary chemical production
Intermediate chemical production
Chemical products
820.3 million tonnes
Secondary reactants
H2O 274.0
O2 221.2
CO2 151.6
N2 142.4
H3PO4 60.8
Other 109.4
Secondary products
CO2 286.8
H2O 140.0
CH4 42.8
HCl 24.9
CaCl2 7.7
Other 312.8
Ammonia & methyl alcohol
Fertilizers & pre-cursors
Coal 55.0
Ammonia
Urea
N-fertilizers 274.7
Mono-/di-ammonium phosphate
Ammonium sulphate
Methyl alcohol
Ammonium nitrate
Nitric acid
Fertilizers
Natural gas & NGLs 198.6
Light feed
Monomers & polymers
Ethylene
Polyethylene
Thermoplastics 222.2
Heavy feed
On-purpose processes
Vinyl chloride
Polyvinyl chloride
Liquid oil products 259.8
Propylene
Polypropylene
Polystyrene
Thermosets, fibre & elastomers 107.2
Steam cracking
Styrene
Polyethylene terephthalate
Carbon black
C4 stream
Ethylene glycol
Polymers
Toluene conversion
Refinery-sourced olefins & aromatics 162.6
BTX aromatics
Terephthalic acid
Solvents, additives & explosives 107.3
Polyamides
Intermediates (1)
Intermediates (2)
Intermediates (3)
Other 108.9
Global chemical sector flows
Values in million tonnes for 2013 (Mt yr-1)
Peter G. Levi, Jonathan M. Cullen
ISIE-ISSST Chicago, June 2017
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Thank you!

Questions and comments welcome

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