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Achieving a sustainable circular economy in the chemical industry – The case of waste-based olefin production

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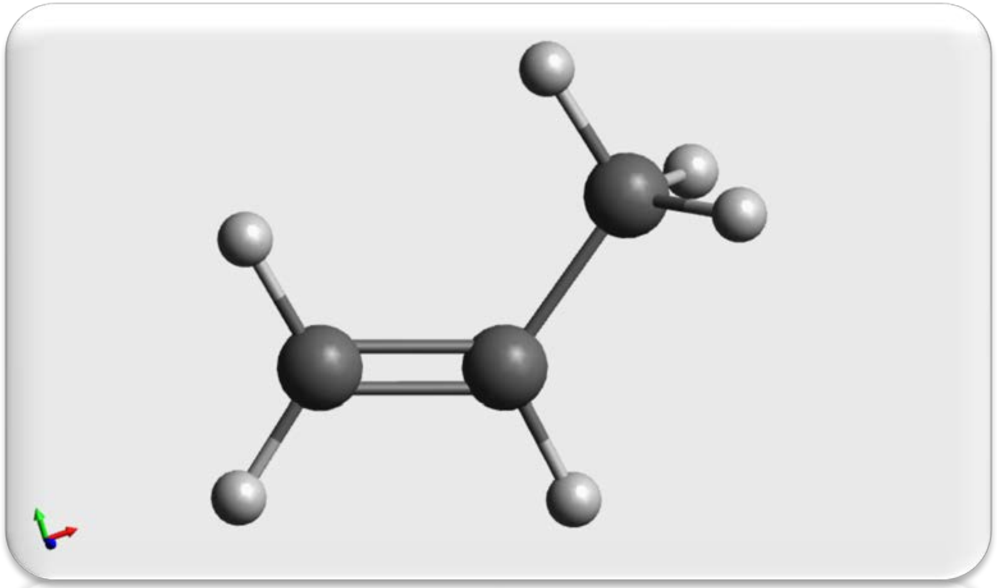

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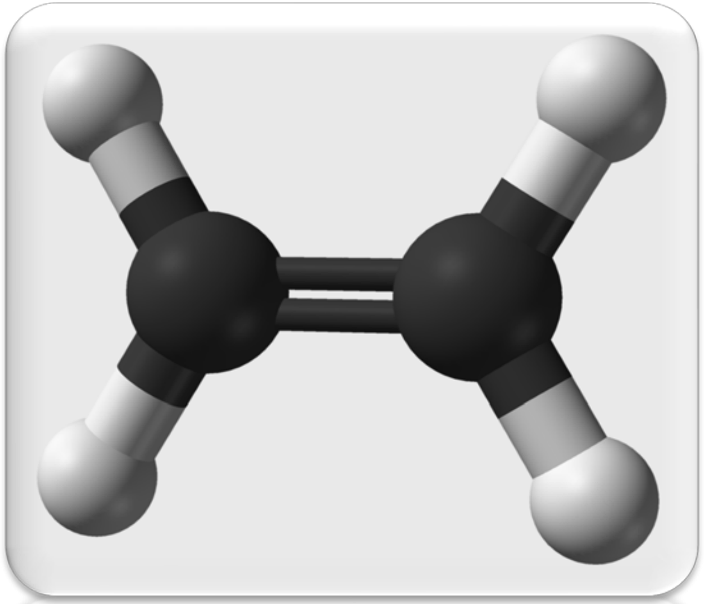

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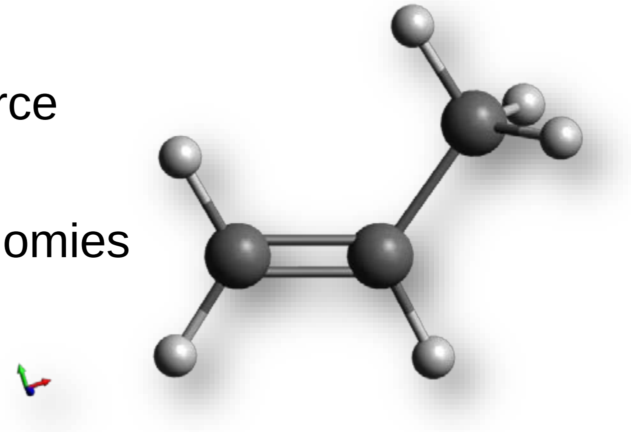
Motivation & aim

- Climate-neutral economies demand a re-shaping of production processes which
  - fulfil the demands for a circular economy based understanding of resource efficiency, and
  - support climate-neutrality, but also a sustainable transformation of economies

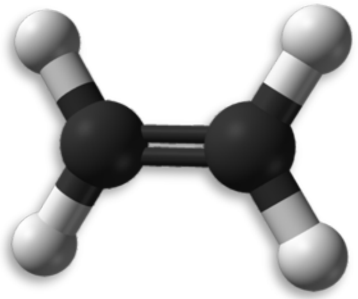
- Appropriate system concepts and technologies are needed

➔ A concept could be circularity; a technology could be chemical recycling

- Aim: Assessing the sustainability of chemical recycling technology to produce olefin as an approach for circularity in the chemical industry



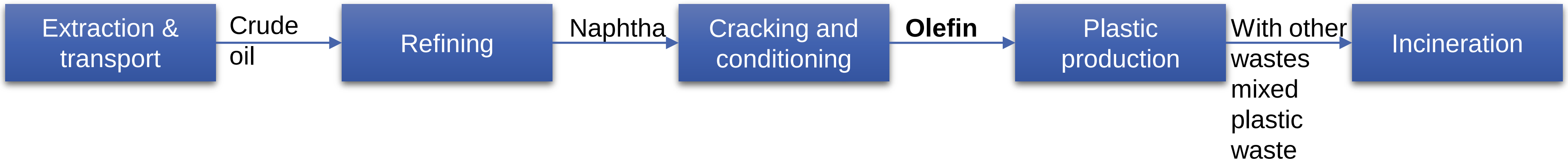
Propylene



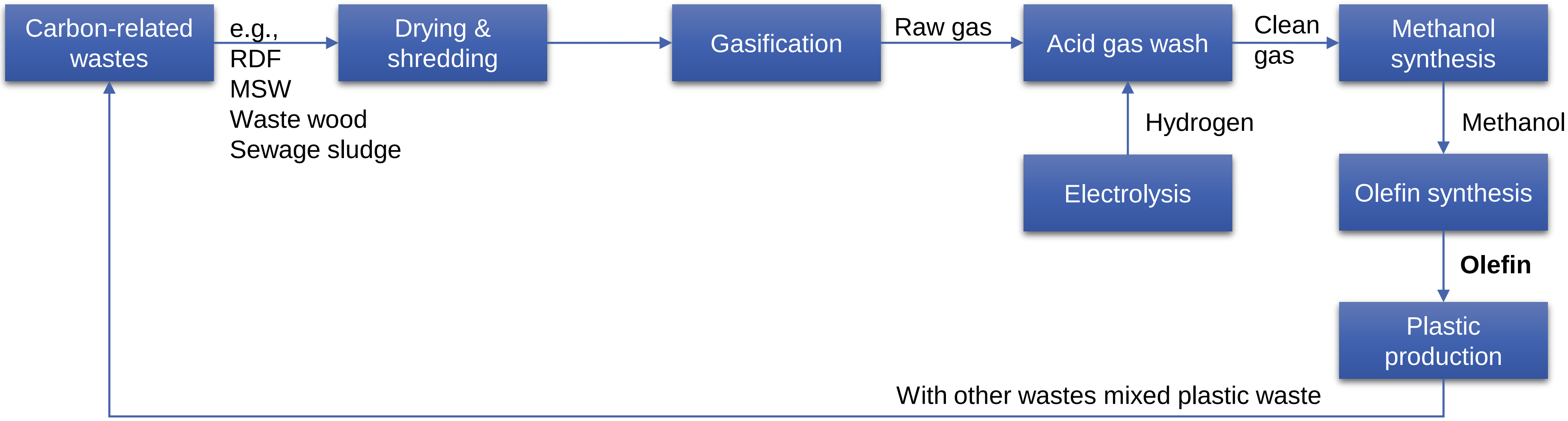
Ethylene

Producing olefin – linear vs. circular

Current, linear carbon system, i.e. Steamcracking (simplified)



Methanol-to-olefin (MtO) synthesis (simplified)



RDF: Refuse-derived fuel
MSW: (Non-organic) municipal solid waste

Main assumptions and scenarios

- System boundary: Germany in 2045
  - 90% reduction of CO_{2eq} compared to 1990
  - Annual GDP growth rate 0.8% (from 2015)
  - No decisive structural change of the economy, although technical progress is considered

➡ Olefin production in 2045: 10.8 Mio. t/a

- Considered wastes

Wastes	Availability in 2045
Refuse-derived fuel (RDF)	14.2 Mio. t
Non-organic municipal solid waste (MSW)	12.9 Mio. t
Waste wood (WW)	5.7 Mio. t
Sewage sludge (SL)	2.1 Mio. t

- Scenarios

Scenario	Technology	Waste inputs
Business-as-usual	Steamcracking (Naphtha)	--
RDF-MSW	MtO-Synthesis	RDF: 8.7 Mio. t MSW: 2.1 Mio. t
RDF-MSW-WW	MtO-Synthesis	RDF: 8.7 Mio. t MSW-WW: 2.1 Mio. t
RDF-WW-MSW	MtO-Synthesis	RDF-WW 8.3 Mio. t MSW: 2.5 Mio. t
RDF-SL-WW	MtO-Synthesis	RDF-WW: 8.3 Mio. t RDF-SL: 2.5 Mio. t

Notes

- MtO-Synthesis – Methanol to olefin-Synthesis
- Each MtO-Synthesis scenario consists of two “technology variants”, defined by the selected wastes
- Amount of waste input depends on caloric value and availability of wastes

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Assessment method, selected criteria and indicators

- Conceptual base: Integrative Concept of Sustainability (ICoS)
- Selection of criteria and indicators: literature, knowledge of experts, and own expertise

		Criterion	Indicator
Health	1	Greenhouse gas (GHG) emissions	*Mio. t $CO_{2eq.}$*
	2	Particular matter emissions	*kt PM10*
	3	Nitrogen emissions	*kt NOx*
Climate, Environment, Resources	4	Use of renewables (Resource efficiency of olefin production)	*t Output / t Input*
	5	Global warming potential	*Mio. t $CO_{2eq.}$*
	6	Acidification potential	*kt $SO_{2eq.}$*
Economy	7	Employment	*persons*
	8	Value added	*€ gross value added*
	9	Market acceptance	*numerical score*
Society	10	Local acceptance	*numerical score*
	11	Landscape (Land use change)	*ha*

- Calculation of indicators: adapted MFA-model CarboMoG
  Exceptions: market and local acceptance

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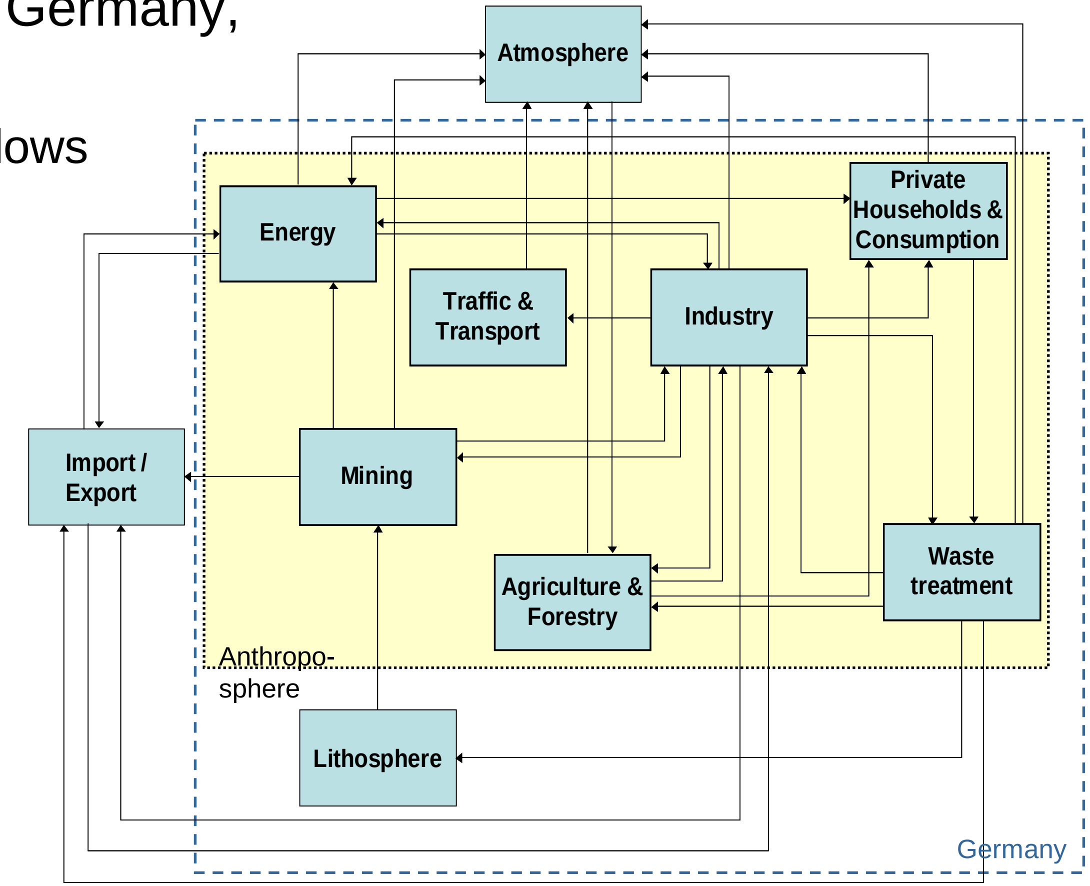
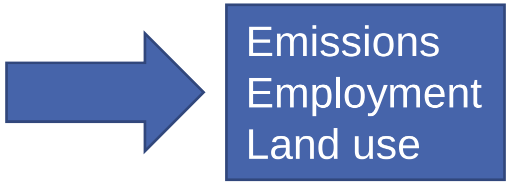
CarboMoG ~ Carbon Flow Model of Germany

- Process-based dynamic material flow model, i.e., time path dependant dynamics
- Geographical system boundary: Germany,
- Scope
  - 225 single material and energy flows
  - 175 (+2) processes
- Final demand driven
- Reference year: 2015
  Target year: 2045





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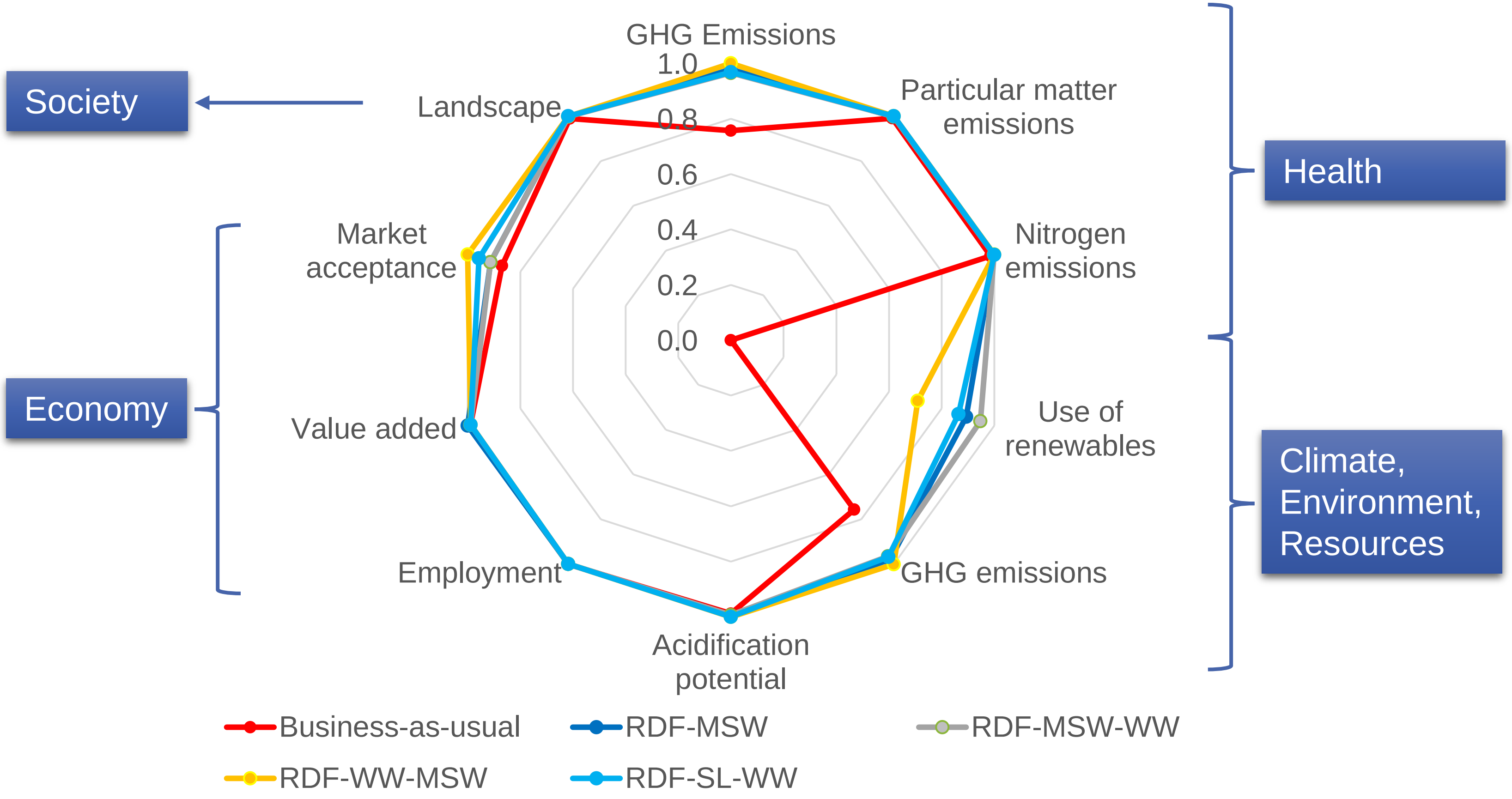
Normalized results



Notes:

- Value 1 indicates the best performance. Values between 0 and 1 indicate the distance to the best performance

- With the exception of employment MtO-Synthesis outperforms Steamcracking
- Only in case of GHG emissions and use of renewables the differences are on a national scale noteworthy
- Market acceptance depends inter alia on price, quality, environmental impacts. Regarding evaluation, environmental impact is the decisive factor, assuming competitive prices
- No waste input combination dominates MtO-Synthesis scenarios
- Local acceptance is unclear: the balance of positive and negative impacts are site specific (e.g., brownfield vs. greenfield investment, demographics, available infrastructure)

Summary & conclusion

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- In the longer run (2045) under German conditions a mixture of carbon-related wastes could substitute Steamcracking completely, using MtO-Synthesis
- Most indicators show a better performance of MtO-Synthesis compared to Steamcracking, but *on a national scale* the differences are – with some exceptions – not significant
  - But the exceptions could be crucial: GHG emissions and use of renewables
  - Looking at single sectors, the differences could be noteworthy,
    - e.g., employment of incineration sector could drop significantly (between one-third and half);
    - e.g., value added of olefin industry could increase by 250%, the one of the incineration sector could drop between one-third and half
- Local acceptance is important, but cannot be assessed satisfactorily over the entire system

- The transformation to a circular waste-based olefin production could pave a way to a *more* sustainable production of chemicals, while supporting the national climate policy
- No closed-loop circular pathway is shown!

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