1 History of the Institute of Energy Process Engineering and Chemical Engineering (IEC)

The history of IEC dates back to 1918, when the Lignite Foundation of the State of Saxony was founded to develop processes and technologies for lignite utilization in Saxony. In 1919, the precursor department of IEC with a focus on the thermochemical conversion of lignite was established. Following the Second World War and the subsequent division of Germany, East Germany was cut off from energy imports. During this time, R&D efforts to develop coal resources for energetic and chemical utilization intensified and Freiberg grew to become the centre of coal R&D activities in the Eastern Bloc. Between the 1950s and 1960s, the collaboration between the institute and the Deutsches Brennstoffinstitut (German Fuel Institute) established the technology basis for the SIEMENS and CHOREN gasification technologies, which are implemented on a large scale in China today. In 1994, Prof. Dr-Ing Bernd Meyer—following 5 years as the scientific head
for R&D of gasification and power-plant technologies at Rheinbraun AG (today RWE), where he led the development of the High-Pressure Winkler (HTW) gasifier pilot plant in Wesseling and the HTW demonstration plant in Berrenrath in Germany for the co-gasification of coal and waste—took over as institute director and as Professor for Energy Process Engineering and Thermal Waste Treatment. With his extensive professional experience and interest to resolve challenges faced by the industry relating to carbon-conversion technologies, IEC not only intensified its R&D cooperation with the industry, but also extended from laboratory- and bench-scale facilities towards pilot-scale plants. Highlights include technology consulting activities for Schwarze Pumpe to stabilize the operation of BGL gasification for waste and coal gasification (1997–2007), the collaboration with LURGI to further develop and improve LURGI technologies, i.e. High Pressure Partial Oxidation (HP-POX), ATR, MPG (2003–2011) and the development of diverse pilot-plant facilities at IEC (HP-POX in 2003, Syngas-To-Fuel (STF) plant in 2010, FlexiSlag gasification pilot plant in 2013, GSP gasification pilot plant in 2018 and RECTISOL pilot plant currently under construction). The latest developments are the integration of the business unit on Chemical Conversion Processes of the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in 2017 at Prof. Meyer's Professorship and the establishment of a Fraunhofer IMWS Branch Office on ‘Circular Carbon Technologies’ in Freiberg in 2019. Today, IEC is not only the largest institute at TU Bergakademie Freiberg in terms of personnel and R&D funding; it is also the largest university institute worldwide that is active in the field of gasification technologies.

2 Mission

Coal, biomass and carbonaceous wastes are valuable primary and secondary carbon carriers. Their energetic utilization through power generation and waste incineration represents a linear 'cradle-to-grave' production and utilization route that is not only associated with significant emissions of greenhouse gases, trace components and fine dust, but is also a waste of valuable carbonaceous resources. Following the Paris Agreement, the global drive towards reducing the carbon footprint has been accelerated. At the same time, there is also increasing pressure on industries to increase resource efficiency, conserve primary carbonaceous resources and reduce carbon leakage. To address these global developments and trends, IEC investigates a wide range of issues and future demands associated with closing the carbon cycle and the role of carbon resources (e.g. coal, biomass, carbonaceous waste, etc.) in a circular economy.

IEC’s R&D and education profiles focus on innovative processes, technologies and systems for sectors ranging from energy, chemical, waste and metallurgy to processing industries. Key objectives are the increased efficiency and minimization of CO₂ and other environment-polluting emissions associated with the thermochemical conversion of primary and secondary carbon resources. These include fossil as well as renewable energy resources such as crude oil, natural gas, coal, biomass, carbon-containing waste and CO₂ (see Fig. 1 for some examples of primary and secondary carbon resources that IEC is focusing on in its R&D activities). Through a coupling with renewable energy (‘green’ electricity, ‘green’ hydrogen) and the chemical recycling of secondary carbon resources, the journey towards CO₂-emissions-free chemical production can be achieved and technically realized. Our R&D activities thus make a critical contribution to the successful and sustainable transformation of the energy and raw material sectors from a linear to a circular carbon economy in Germany.

To accomplish this mission, modern energy process engineering methods ranging from experimental process simulation and evaluation, computational fluid dynamics (CFD), reactive fluid dynamics simulation, stationary and dynamic flowsheet process chains simulation, mineral phase behaviour and thermochemical process analysis are utilized in combination with laboratory-scale, bench-scale and large-scale facilities. The interdisciplinary integration with chemistry

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Fig. 1 From top left: (a) Residue-derived-fuel pellets, (b) shredder fractions, (c) ocean waste, (d) coal, (e) wood chips, (f) shredded wood, (g) peat, (h) petcoke
3 Research divisions

With a team of over 100 scientists and technical specialists, IEC’s eight research divisions are clustered under four main categories as illustrated in Fig. 2 and described below:

3.1 Feedstock and conversion

- Mineral matter—focus on mineral matter behaviour in high temperature conversion processes such as gasification and combustion (e.g. chemical and physical characterization, viscosity, ash/slag formation and behaviour, etc.).
  - More information available at https://tu-freiberg.de/en/iec/evt/groups/mineral-matter-mm.
- Thermochemical conversion—focus on beneficiation and conversion of biomass, coal, wastes and residues by pyrolysis, gasification or related processes (e.g. characterization of thermochemical behaviour, kinetics, energy and material balances, reactivity, coke and char production, etc.).
  - More information available at https://tu-freiberg.de/en/iec/evt/groups/thermochemical-conversion-tcc.

3.2 Process and components

- CFD modelling—focus on modelling of high temperature processes across the entire spectrum ranging from chemically reacting particles to the complete reactor (e.g. fixed-bed, fluidized-bed, entrained-flow in metallurgy and chemical engineering, advanced submodels development, etc.).
  - More information available at https://tu-freiberg.de/en/iec/evt/groups/cfd-modeling-of-high-temperature-processes-cfd & https://tu-freiberg.de/en/virtuhcon.

Fig. 2 (a) IEC’s scientists and technical specialists; (b) IEC’s research divisions
• Plant operation—focus on design, construction and operation of bench-scale and large-scale pilot plants as Fig. 3 illustrates. These plants enable investigation, process development, equipment performance assessment and optimization under industrial operating conditions.
  - More information available at https://tu-freiberg.de/en/iec/evt/groups/plant-operation-po.

3.3 Technologies

• Technologies for solid-fuels gasification—focus on development and optimization of commercial/future gasifiers for the chemical conversion and utilization of carbon resources (e.g. technology evaluation, plant concepts, CAPEX and OPEX, reactor designs, feedstock blending and feeding, etc.).
  - More information available at https://tu-freiberg.de/en/iec/evt/groups/technologies-for-solid-fuels-gasification-tsg.
• Syngas technologies—focus on modelling, planning, evaluation and test campaigns for synthesis gas generation through high pressure synthesis gas plant for the gasification of liquid and gaseous carbon feedstock (HP-POX) and for the generation of high octane gasoline out of synthesis gas (STF) via a gasoline synthesis plant. In addition, further development of gasoline synthesis is carried out on a lab scale (STF+ test plant).
  - More information available at https://tu-freiberg.de/en/iec/evt/groups/technologies-for-solid-fuels-gasification-tsg.

![Fig. 3 IEC's pilot-scale gasification technologies and suitable feedstock](image-url)
3.4 Systems

- Technology assessment—focus on integrated assessment of social-technological-economical-environmental-political (STEEP) impacts along technological and resources chains (e.g. life-cycle assessment, risk perception, risk assessment, public acceptability, science and technical communication, etc.).
  - More information available at https://tu-freiberg.de/en/iec/evt/groups/technology-assessment-ta & https://tu-freiberg.de/en/steep-carbontrans.

- Process-chain development—focus on realistic simulation of complex process chains and holistic system evaluation using a large number of validated process models (e.g. concept development and modelling, detailed material and energy balancing and optimization of processes and systems, upscaling of plants and processes, dynamic process behaviour, feasibility studies, etc.).
  - More information available at https://tu-freiberg.de/en/iec/evt/groups/process-chain-development-pcd.

Our focus is on developing solutions that can be used directly by the industry for the effective and sustainable utilization of solid (e.g. biomass, coal, petcoke, all types of waste, etc.), liquid (e.g. oil, heavy residues, etc.) and gaseous (e.g. natural gas, etc.) carbonaceous feedstock. To achieve this, we are developing predictive simulation capabilities supported by strong interaction between our experimental and modelling teams, and validation of the results with data obtained from our large-scale facilities and from industrial partners.

4 Gasification Technology Center at IEC

Being the leading R&D institute for large-scale gasification processes in Europe, our gasification competence and expertise include a full spectrum of pilot-scale gasification technologies that are suitable for diverse carbon feedstock ranging from natural gas, oil, slurries, coal, biomass to liquid and solid waste.

5 R&D highlights

5.1 FlexiSlag gasification technology

Our innovative fixed-bed slagging gasification technology (Fig. 4) is suitable for flexible feedstock (e.g. biomass, coal, petcoke, 100% waste). Products are high quality syngas without oil and tar as well as environmentally neutral glassy slag (metals separable via magnet or eddy currents). Besides 100% coal gasification, we successfully carried out 100% (plastic) waste and 100% petcoke gasification in 2018 for industrial application at 40 bar.

5.2 Entrained-flow gasification technology

Entrained-flow gasification technology has the largest market share in the world. To develop realistic simulation of the whole entrained-flow gasifier to support the development of next-generation entrained-flow gasification technologies, we carried out fundamental research (e.g. experimental activities for kinetics and single-particle behaviour) to facilitate the development of CFD submodels of single particles that in turn support our realistic simulation of the whole entrained-flow gasifier as illustrated in Fig. 5.
5.3 HP-POX gasification technology

Our HP-POX pilot plant operates up to 100 bar. It is suitable for flexible liquid and gaseous feedstock (e.g. oil, natural gas, heavy residues). It has a unique feature that allows direct optical access to the flame. This supports our predictive-simulation activities by allowing us to validate new burners and reactor designs that are developed using our CFD models and assess whether actual flame behaviour is as simulated by our CFD team (Fig. 6).

6 Beyond science and technology to society and politics

The successful transformation from a linear to a circular carbon economy requires intersectoral cooperation between key market players as well as supporting political frameworks and regulations. To support this, IEC R&D activities are focusing not only on innovation and demonstration, but also on market transfer. Some examples are as follows.

6.1 National Network for a Circular Carbon Economy (NK2–Netzwerk Kohlenstoffkreislaufwirtschaft)

IEC has established the intersectoral National Network for a Circular Carbon Economy in Germany in cooperation with Fraunhofer IMWS. The vision of the industry partners from the energy, chemical, waste management and recycling as well as engineering sectors is the sustainable utilization of primary and secondary carbon resources such that carbon is retained in the system instead of being emitted as CO₂ into the environment. This network was established in July 2019 and includes partners such as Air Liquide, Arvos, BASF, COVESTRO, DOMO, DOW, LyondellBasell, ROMONTA, RWE, SRW metalfloat GmbH, TA Lauta/STEAG, etc. In addition to promoting intersectoral exchanges to facilitate the identification of potential synergies and opportunities, it also provides a platform for dialogue with policymakers and regulators on the necessary political framework to support the transformation towards a circular carbon economy (Fig. 7).
6.2 International Freiberg Conference on IGCC & XtL Technologies

Since 2005, IEC has organized the International Freiberg Conference on IGCC & XtL Technologies—a leading international conference addressing a wide range of topics relating to the thermochemical conversion of carbonaceous feedstock and related process chains. The event provides a high-level discussion forum to facilitate the exchange of information and expertise between industry, scientific and political stakeholders along carbon value chains from extraction, processing/refining to conversion, utilization and chemical recycling. Participants come from diverse fields and industrial branches ranging from researchers and specialists engaged in fundamental and applied R&D to industry experts from energy, natural resource, chemical and recycling sectors as well as equipment and technology providers/manufacturers. In 2020, the 10th International Freiberg Conference on IGCC & XtL Technologies will be held in Shanghai, China with the support of co-organizers Synfuels China Technology Co., Ltd and the East China University of Science and Technology. The focus of the upcoming conference will be on closing the carbon cycle (Fig. 8).

- For more information, visit https://gasification-freiberg.com/about/description/.

6.3 Compact gasification course

To raise industry’s awareness and expertise of innovative processes and technologies for a circular carbon economy, IEC offers intensive courses in the field of gasification technologies that provide a detailed introduction into the scientific fundamentals and technologies of gasification, synthesis gas production and purification as well as IGCC power plants. In addition to providing overview and insights into leading commercialized gasification technologies, the course programme provides an introduction into various simulation software tools as well as the opportunity to visit IEC’s extensive laboratory and bench-scale and large-scale pilot-plant facilities (Fig. 9).

- For more information, visit https://tu-freiberg.de/en/iec/evt/events/compact-courses.
7 Downloads

For an impression of IEC and some of our activities, see the following:

- IEC brochure: https://tu-freiberg.de/sites/default/files/media/professur-fuer-energieverfahrenstechnik-und-thermische-rueckstandsbehandlung-16460/broschuere EVT_web_2018.pdf
- Video 'Overview IEC': https://tu-freiberg.de/sites/default/files/media/institut-fuer-energieverfahrenstechnik-143/IEC Image_07.mp4
- Video 'IEC from a bird’s-eye perspective': https://video.tu-freiberg.de/video/Drohnenflug-vom-IEC/38ebcb5be617591b8aa2038d9c05e6e
- Test campaign in 'FlexiSlag' gasification pilot plant: http://video.tu-freiberg.de/video/IEC-FlexiSlag-Versuchsfahrt/d93347b52f1f1b80a822bb5b5c6c7f1
- Video 'What is chemical recycling': https://video.tu-freiberg.de/video/What-is-chemical-recycling/8ab99ab224cf8ee33006e39f569cb06.

8 Contact

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