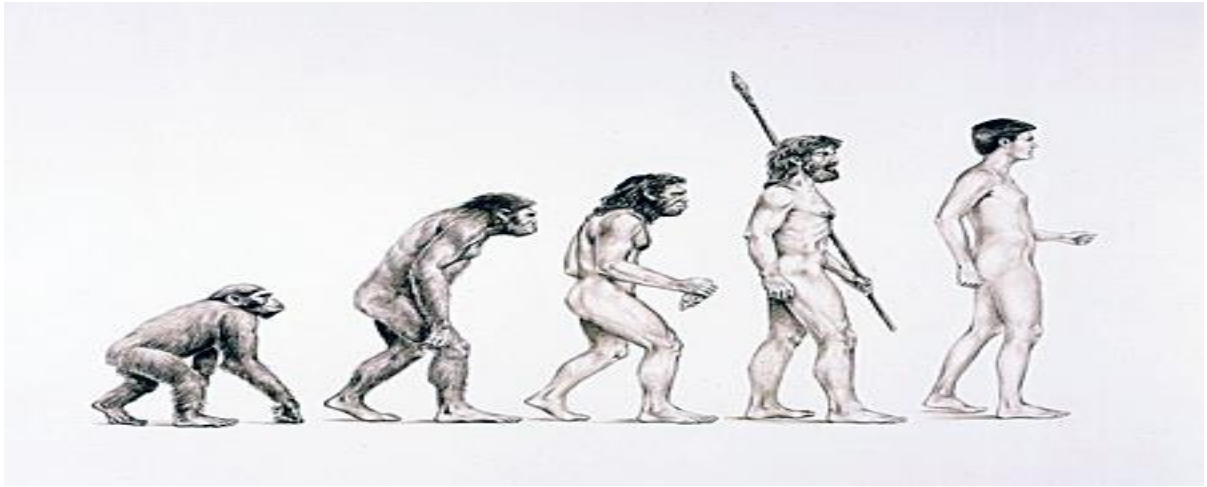
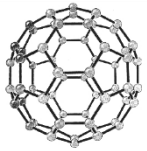
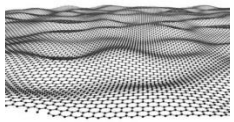
The Evolution of Carbon in the Chemical Industry

Dr. Josef R. Wünsch
BASF SE





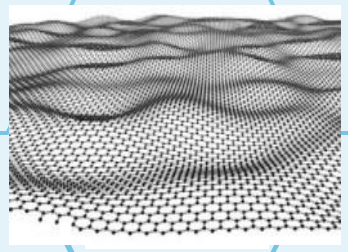


Carbon in the Elemental State

carbon black

carbon fiber

diamond



coke

graphite

activated carbon

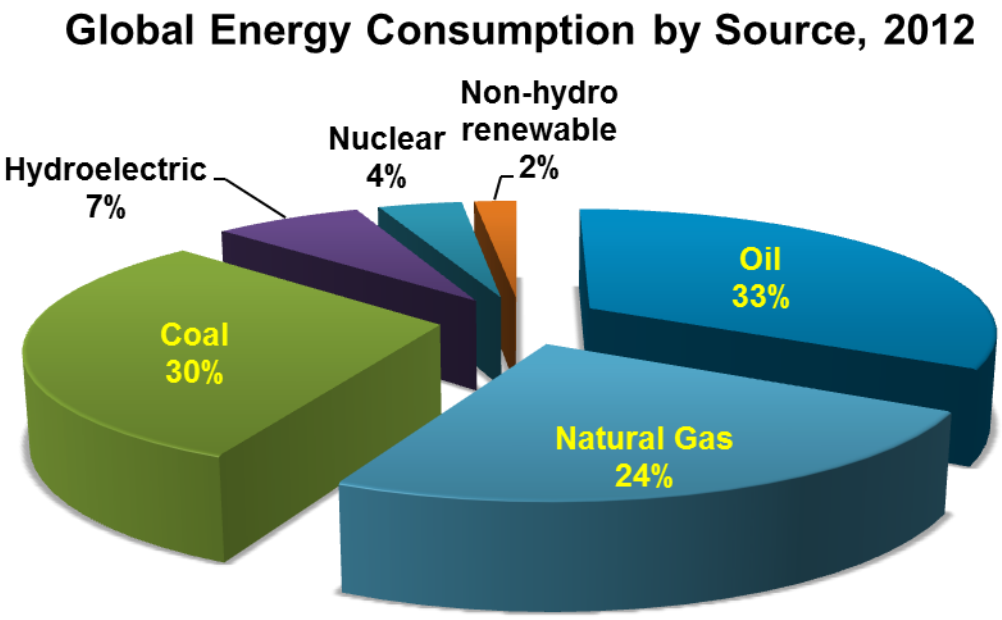
Early Industrial Use of Carbon

- Graphite was used to line the moulds before iron was poured in
- Graphite used as an additive on the outside of cannon balls
- High heat stability ensured higher accuracy when fired

Coal is an Important Energy Source

Coal burning for energy

Gasification



- Fischer-Tropsch process (1925)

  $H_2 + CO \rightarrow C_nH_{(2n+2)} + H_2O$

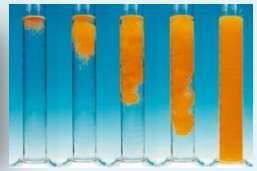
- Coal to Liquid: Creating Synthetic Fuel

Coal is still an important player in the energy landscape

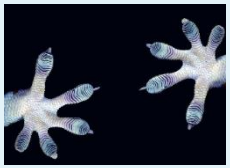
Carbon… the origin of chemistry

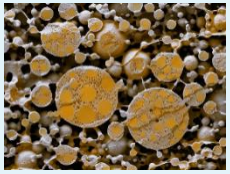
The range of products created by chemical reactions are all derived from carbon feedstock

Dyes and Foodstuffs



Surface Modifiers





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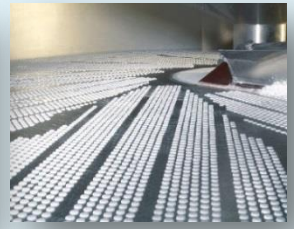
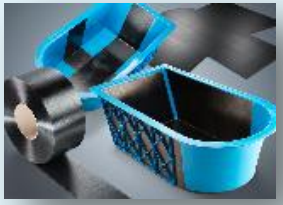
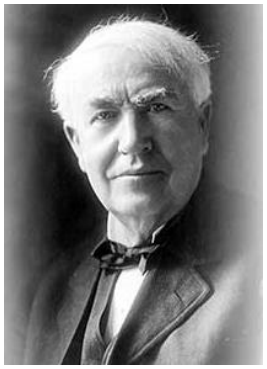
Agricultural Products



Plastics

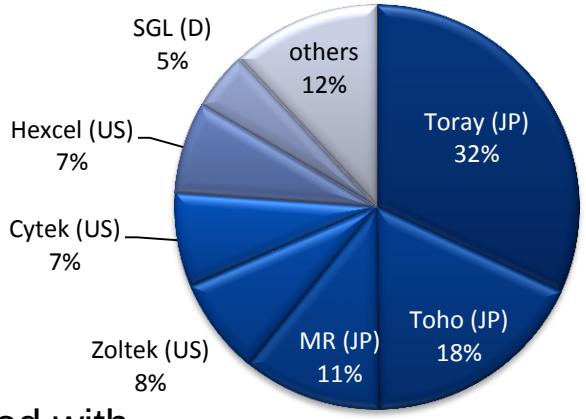


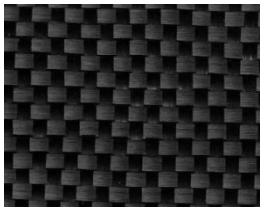
New Carbon Materials: Carbon Fibers

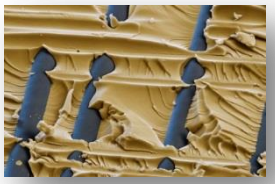


- Thomas Edison used carbon fibers made from cotton or bamboo in early light bulbs
- Low tensile strength but high heat tolerance

Market share of industry leaders







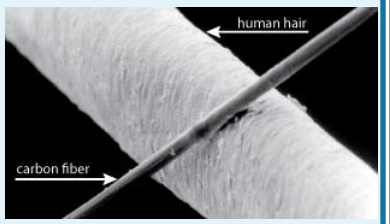
- Production methods improved with polyacrylonitrile as a starting material (AIST Japan)
- First attempt at integrating carbon fiber into an engine by Rolls Royce in the 1960s
- Increased use of **carbon fiber reinforced polymers / composites (CFRPs)**

- 2010: 36.000 t/a
  1,3 bn USD
- 2015: fcst 60,000 t/a

Carbon fibers

Description

- Organic materials pretreated at a high temperature
- Thin strand of material (5-10 µm) which contains 92% to > 99% Carbon
- Feedstocks:
  Polyacrylonitrile (PAN)
  Pitch (coal or petroleum tar)
- Use as reinforcement in Plastics (CFRP)



Properties

- Light weight
- Good fatigue resistance
- High strength and stiffness
- Good conductivity (thermal and electric)
- Chemical inertness (e.g. towards corrosion)
- Low thermal expansion

Applications

Aerospace & Aeronautic
wings, flaps, stabilizers

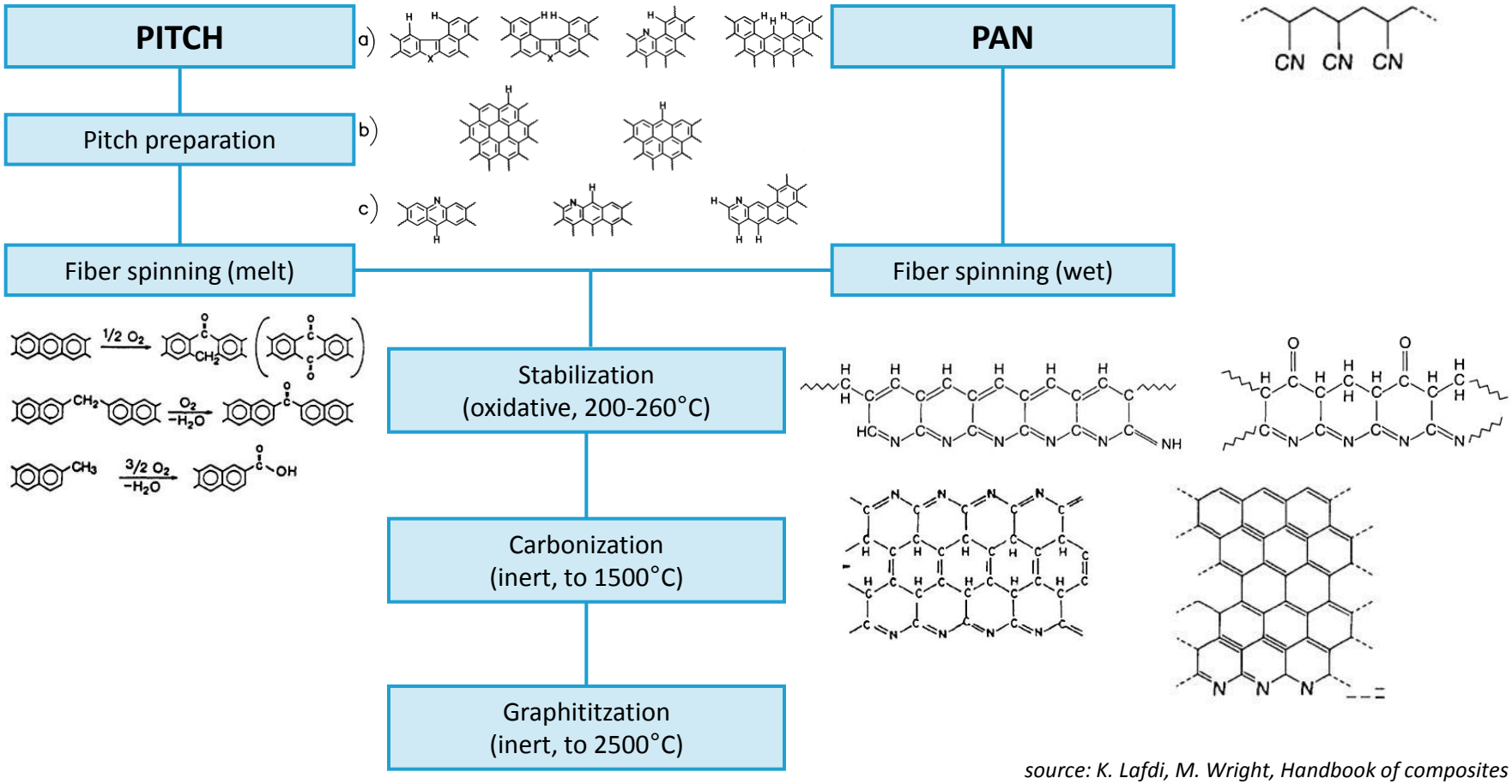
Sport goods
golf shafts, bicylcles, fishing rods, rackets

Automotive
body panels, hoods (premium sport cars)

Wind energy
turbine blades

Carbon fibers
Manufacturing of Carbon fibers

Processes from Pitch and PAN



source: K. Lafdi, M. Wright, Handbook of composites (1998)

Carbon fibers
Value chain

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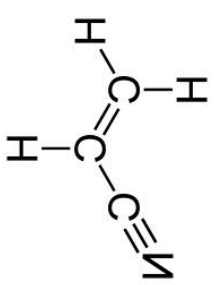

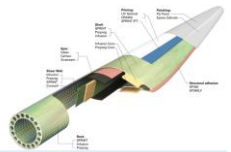

Raw Material	Precursor	Carbon Fiber	Fabrics	Prepregs	Preforms	CFRP*	End-user
Acrylonitrile Pitch	PAN Pitch Rayon	Continuous (Small tow, Large Tow) Chopped & milled Fibers	Multi-axial Unidirectional Woven Braided	Pre-impregnated Compounded	Preformed	Manual lay-up Resin Transfer Molding (RTM) Pultrusion	car chassis, rotor blades, plane wings....

* CRFP = carbon fiber reinforced plastic

INEOS
Asahi Kasei
Petrochina
DSM
...

Toray, Mitsubishi Rayon, Hexcel

Zoltek

Lenzing AG

Toho Tenax, SGL, Cytec

Gurit

Carbotech

Boeing
EADS
BMW
Daimler
Vestas
...

sources:
Lux Research, Inc., SGL website

We Create Chemistry for Sustainable Mobility

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Resources, environment & climate | Food & nutrition | Quality of life

Chemistry enables…

Customer Industries	Transportation	Construction	Consumer Goods	Health & Nutrition	Electronics	Agriculture	Energy & Resources
Growth Fields	Batteries for mobility	Heat management	Enzymes	Medical	Organic Electronics	Plant Biotechnology	**Energy Management**
	Lightweight composites					Functional Crop Care	Rare Earth Metals Recycl.
	Heat management						**Wind Energy**
							Water Solutions
Technology Fields	Raw Material Change						
	Materials Systems & Nanotechnology						
			White Biotechnology				

Growing Demand for Carbon Fiber Composite Technology

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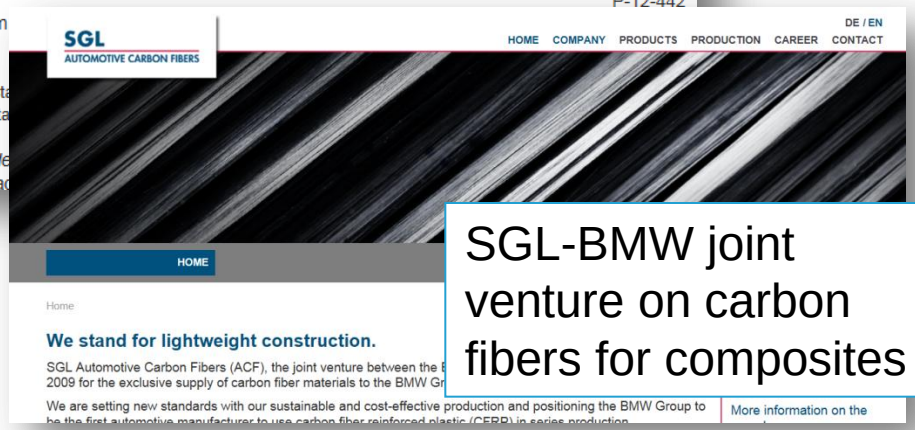
BASF and SGL Group on the Way to Reactive Polyamide-Carbon Fiber Composites

2012-10-04
P-12-442

Joint press release from
Düsseldorf

SGL Group: Hall 8b, sta
BASF: Hall 8b,sta

Ludwigshafen/Wiesbade
material based on a read

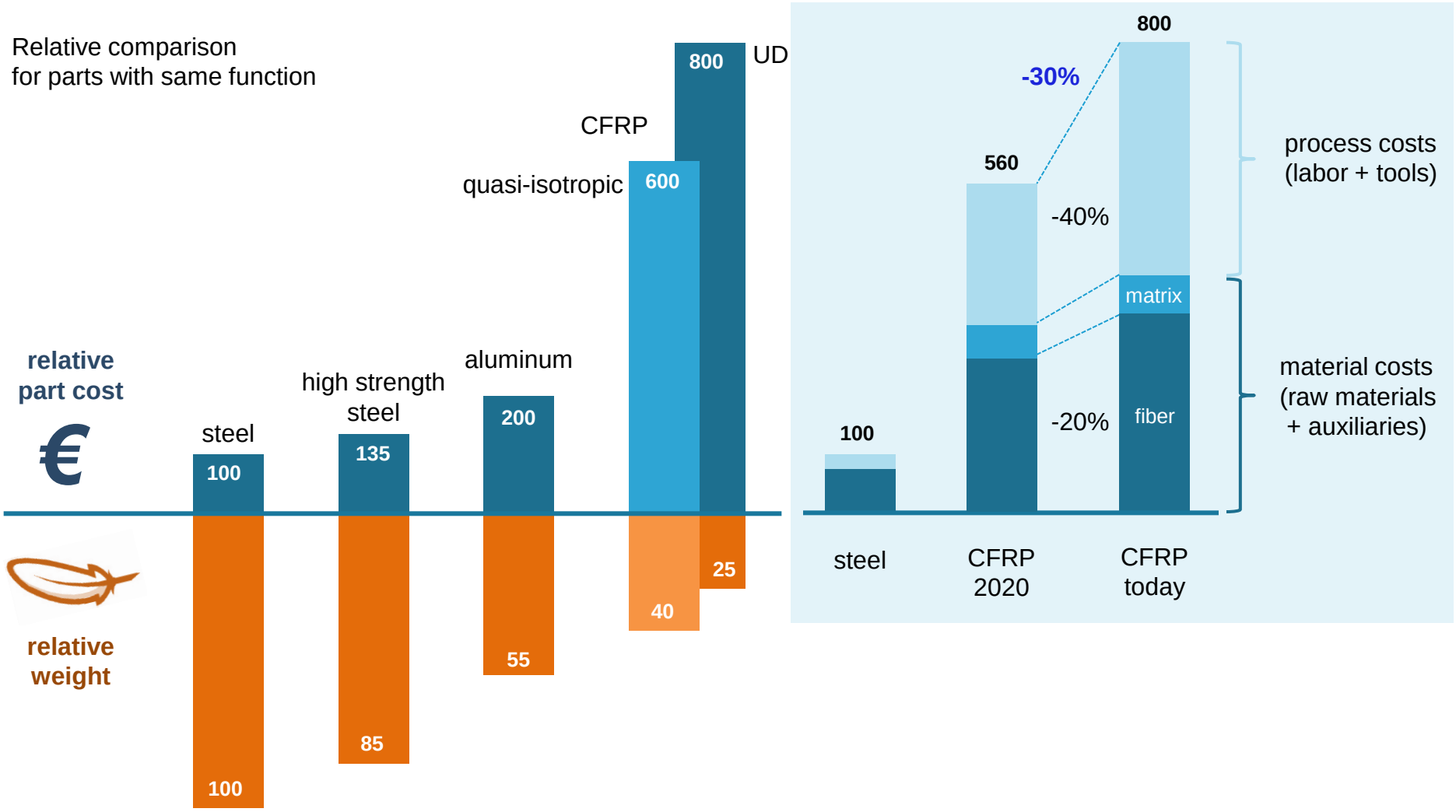


SGL-BMW joint venture on carbon fibers for composites

CARBON FIBRE DEMAND BY REGION BY WEIGHT (2006, 2011 & 2016)

				CAGR %	
Units: '000 tonnes	2006	2011	2016	2006-11	2011-2016
Europe	1.9	4.5	9.9	18%	17%
North America	0.0	1.8	5.7	-	27%
Asia	0.0	1.1	5.7	133%	39%
ROW	0.0	0.4	1.3	-	28%
Total	**1.9**	**7.7**	**22.6**	**32%**	**24%**

Cost of Composite Automotive Parts Need to Be Reduced Along the Value Chain

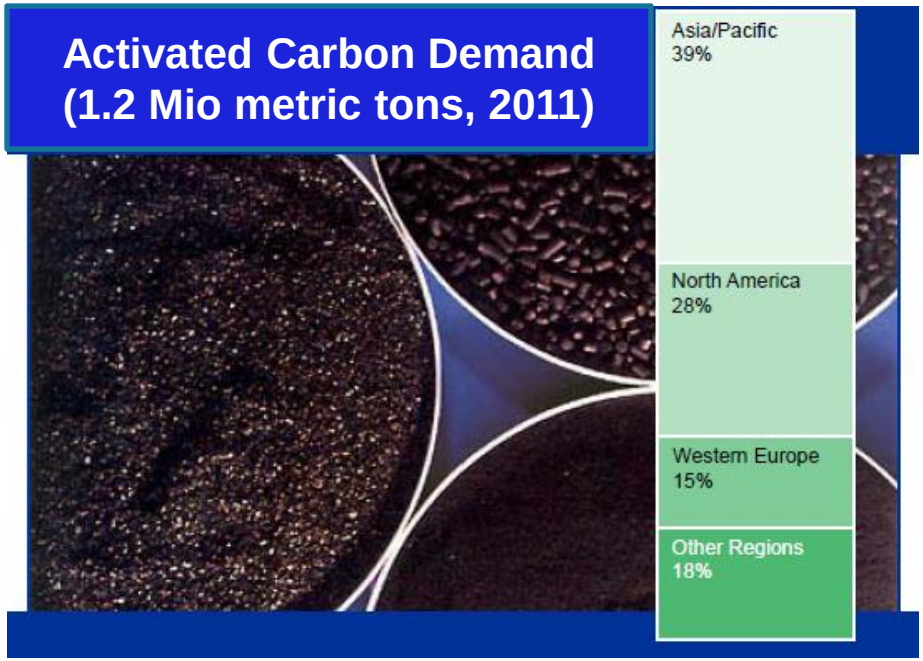


Source: RolandBerger, VDMA, 2012, „Serienproduktion von hochfesten Faserverbundteilen“

Diverse Markets for Carbon in Energy Storage

The commodity carbon market is dominated by purification/filtration applications which require high surface area

The carbon market for energy storage is a specialty market, requiring high surface area and/or electrical conductivity

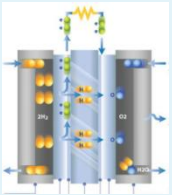


Source: Freedonia

- Lithium-ion battery anodes (graphite, carbon black)

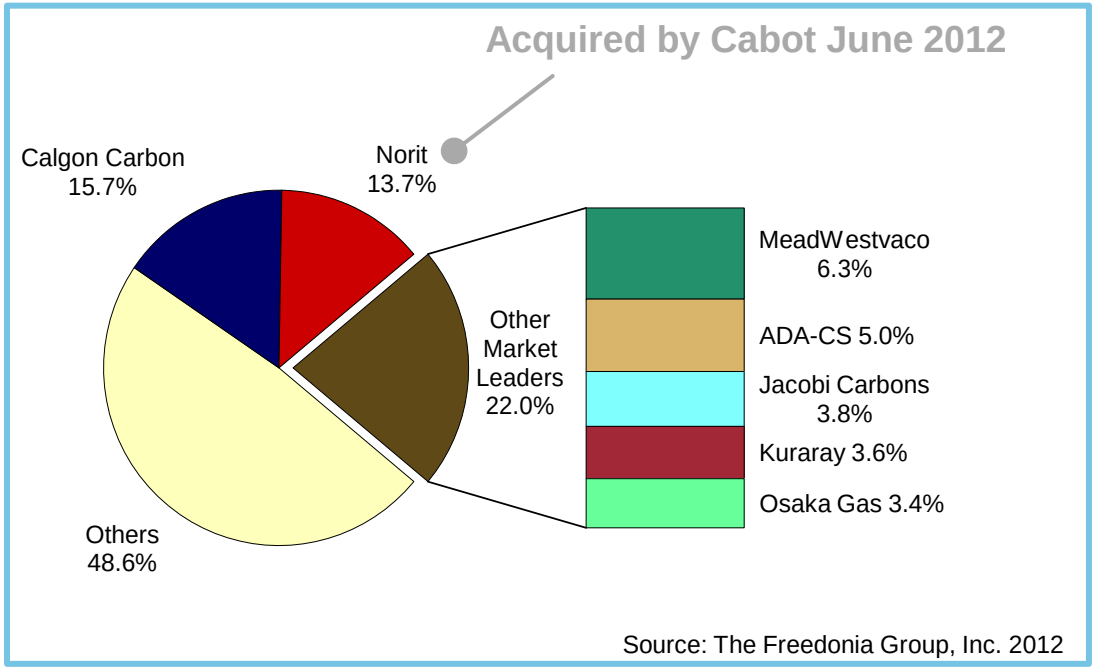
- Supercapacitor electrodes (activated carbon)

- Fuel cell catalyst support (graphite)



Activated Carbon World Market

AC Consumption	2011 [kt/a]	2016 [kt/a]	Growth p. a. 2011-2016
Global	1.180	1.930	10.3 %



Markets

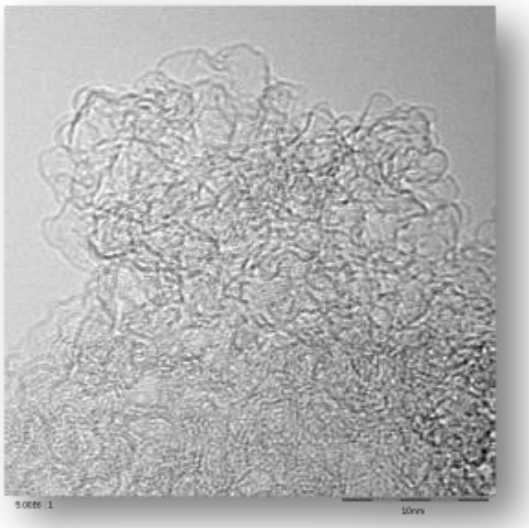
- 40% water treatment,
- 40% air & gas purification
- 10% food processing
- 10% chemical, pharma & others

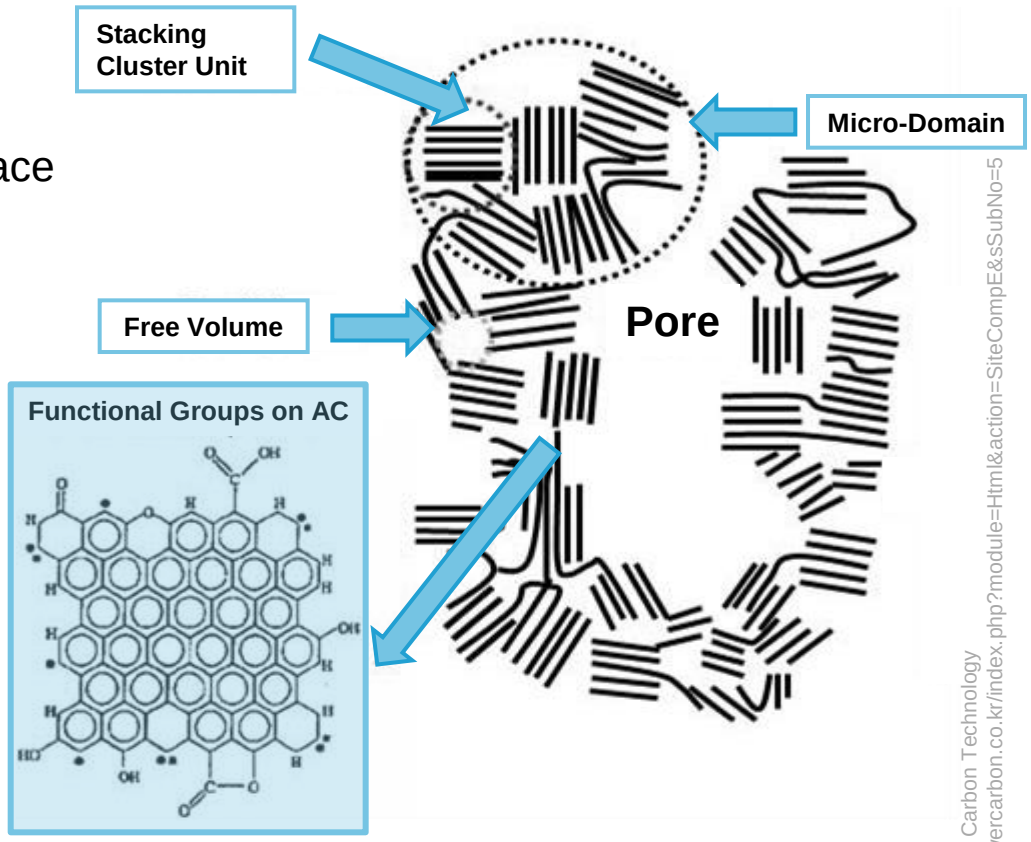
Relevant Markets for BASF

- Supercapacitors
- Catalyst Supports
- Batteries & Electrodes
- Solvent Vapor Recovery
- CH_4 Storage
- Protective

Structure of Activated Carbon

- **“Steel wool” structure model**
  - entangled single carbon layers
  - enclosed voids form porosity & surface

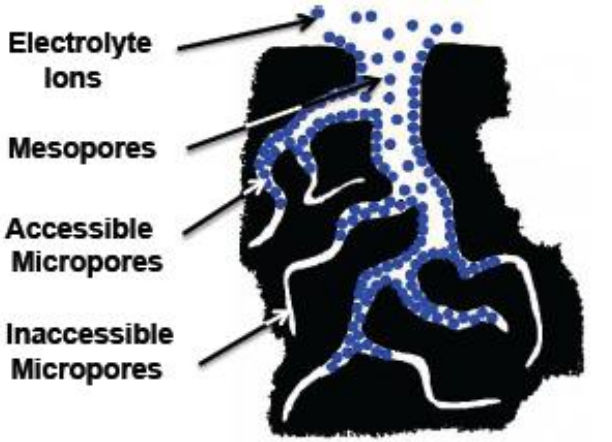




Source: Power Carbon Technology
http://www.powercarbon.co.kr/index.php?module=Html&action=SiteCompE&sSubNo=5

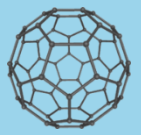
Requirements for Supercapacitors

- **Major Requirements on AC**
  - High surface area (BET > 2000 m^2/g)
  - Defined pore size distribution
  - Micropore volume (d_{pore} < 2 nm)
  - Mesopore volume (d_{pore} > 2 nm)
  - Low impurity content (< 1000 ppm)
  - No chemical and electrical activity
  - Good wettability for electrolyte
  - Uniform particle size distribution (~ 5 µm)
  - High packing density
  - Low electrical resistance



Carbon Electrode Material with Electrolyte

The Emergence of Nano Carbons



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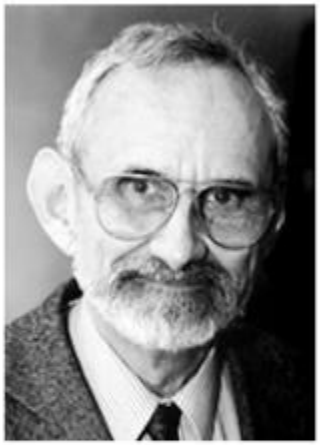
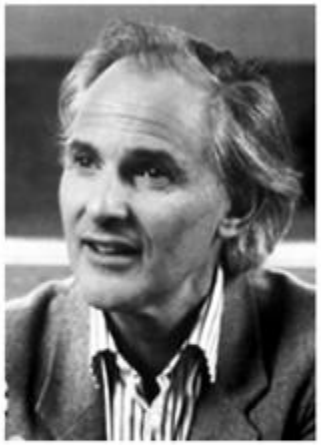
The Nobel Prize in Chemistry 1996

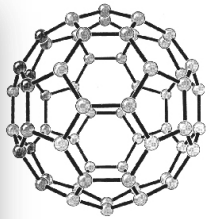
Robert F. Curl Jr., Sir Harold Kroto, Richard E. Smalley





The Nobel Prize in Chemistry 1996 was awarded jointly to Robert F. Curl Jr., Sir Harold W. Kroto and Richard E. Smalley *"for their discovery of fullerenes"*.

Named after Buckmister Fuller, designer of the geodesic dome



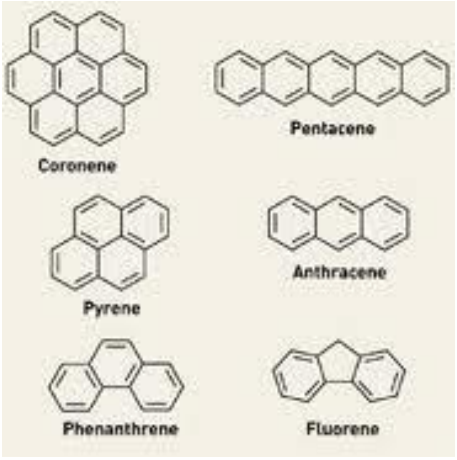
- The discovery of fullerenes paved the way toward tailored syntheses of complex carbon materials
- With electronic characteristics that expanded the use of organic molecules into electronics
- Very good n-dopant material for organic photovoltaics

Dyes and Organic Electronics

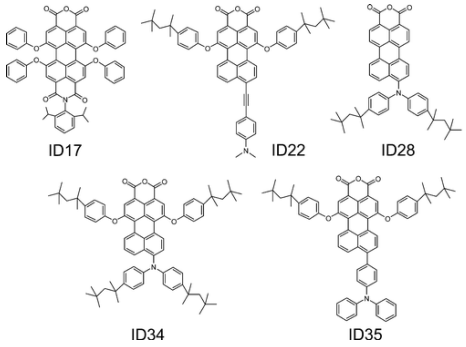
- The chemistry and physics of conducting molecules and polymers developed into the field of organic electronics

Ever increasing adoption of organic electronics into systems

From the building blocks:



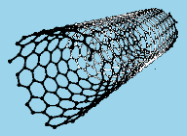
Synthesis of new dyes for DSSCs, with several contributions from Prof. Müllen



Organic PV in smart4vision

Carbon Nanotubes

Enhancement of Mechanical and Electrical Properties



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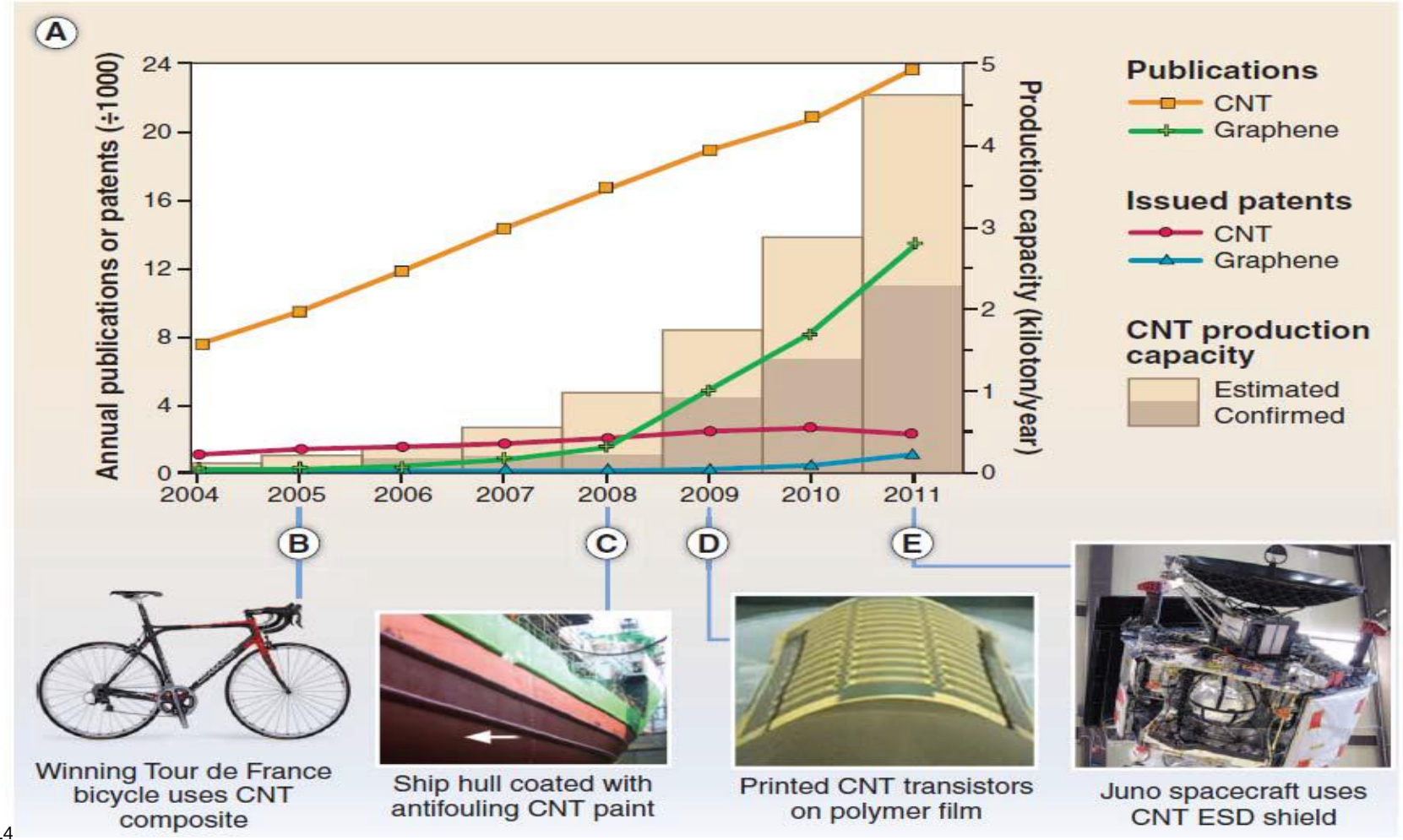
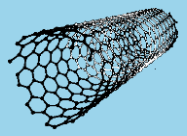
CNT Application Milestones



Carbon Nanotubes

1-Dimensionality



- Production of CNTs undertaken by several companies
- Most notable is the divestiture of CNT business by BayerMaterialScience in 2013
- Key to success is system enhancement and integration rather than large scale production of CNTs

- BASF product: Ultraform® N2320 C for fuel filter housing
- MWCNT filler
- Launched in 2009, used by Bosch in Audi A4 and A5

Graphene is a fascinating nanomaterial

…in one dimension

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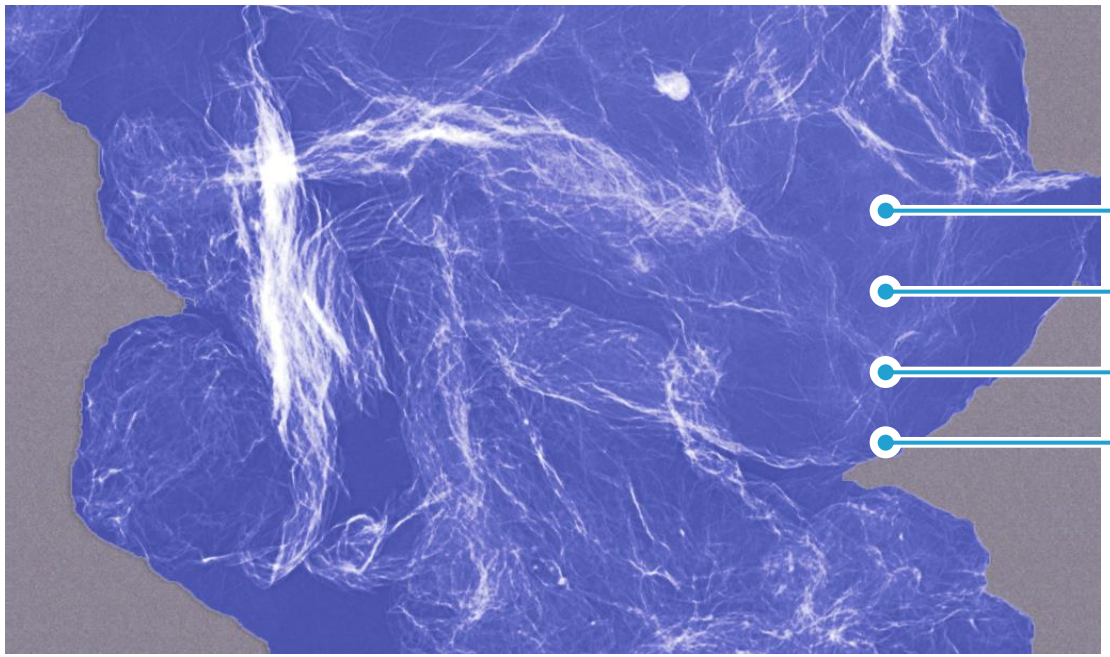
Lateral Dimensions = Micrometer

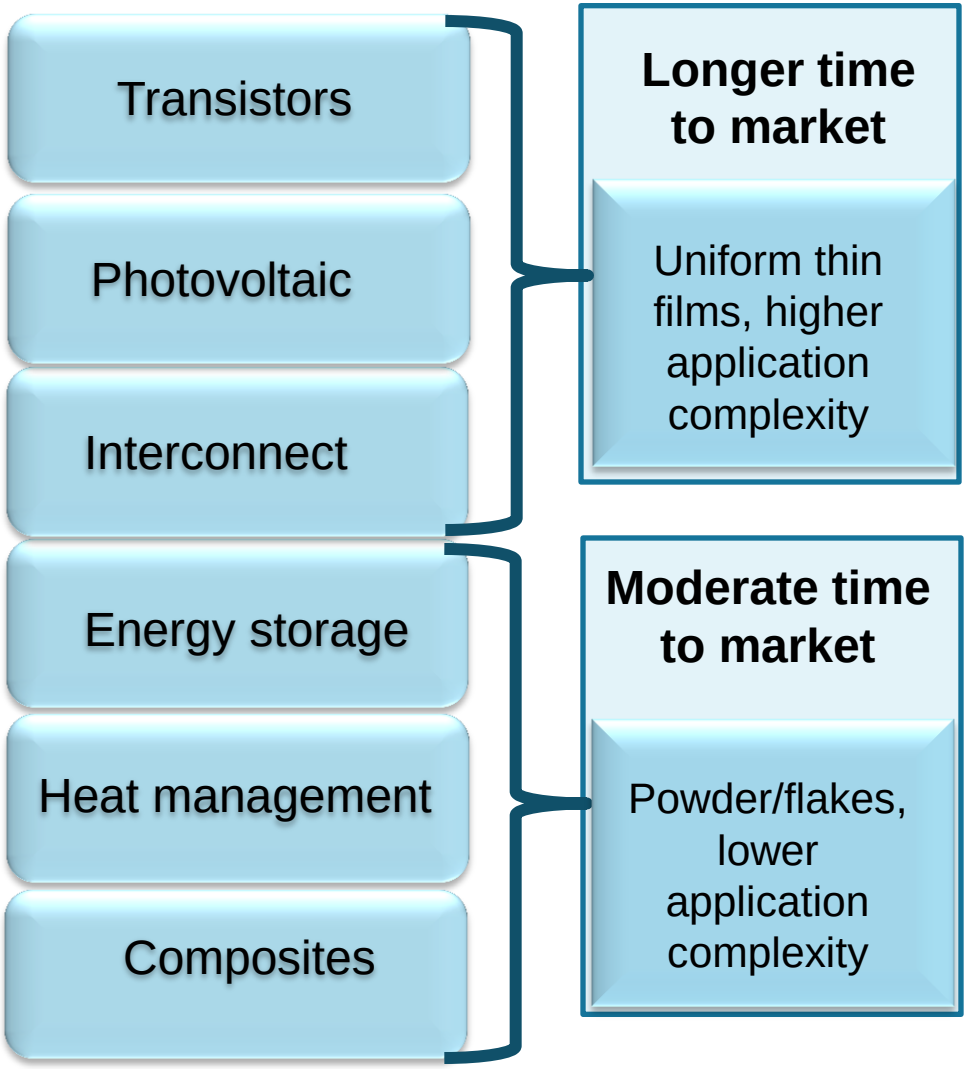
Thickness = Nanometer



- High electron mobility
- High thermal conductivity
- High transparency
- High mechanical strength

Promising Properties of Graphene

Property	Values comparison
Mobility ($cm^2/V•s$)	Graphene – 200k Si – 1400 GaAs - 8500
Transparency (%)	Graphene – 97.7
Resistivity (μΩcm)	Graphene - 10 Doped graphene – 4.02 Cu – 1.68 Pt – 10.6
Surface area (m^2/g)	Graphene - 2630 Activated C - 500 Silica - 800
Thermal conductivity (W/m•K)	Graphene - 5300 Silicon – 149 Diamond - 2320
Ultimate strength (GPa)	Graphene – 130 C-fiber – 4 Steel - 1



The Carbon Materials Innovation Center at BASF

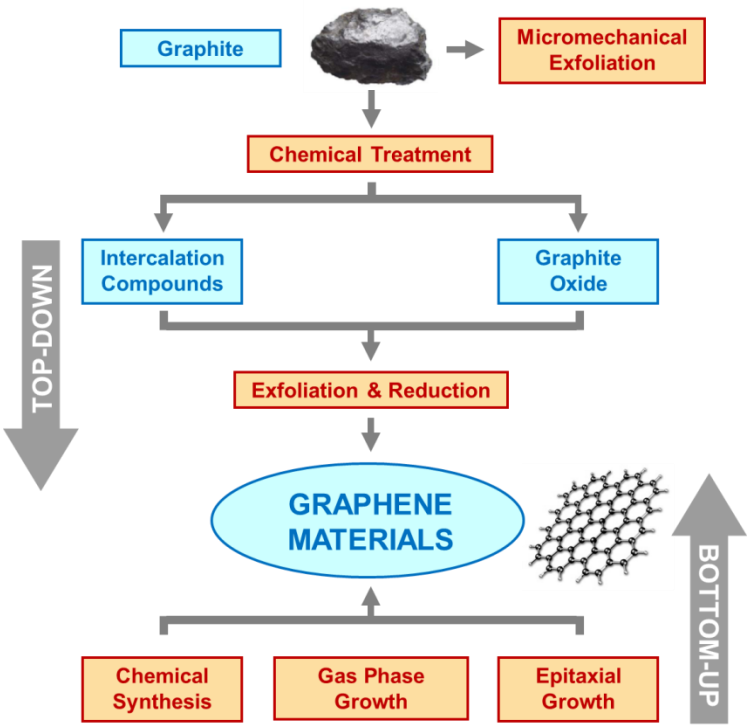
Joint research laboratory leveraging knowledge of BASF and MPI-P

- Facts & Figures:
  - First co-location lab on BASF site
  - 8 Postdocs, 4 BASF employees
  - Total investment over 3 years: €10 million
- Among the Focus Fields:
  - Energy Storage Materials
  - Catalysis
  - Transparent Conductive Layers
  - Carbon Semiconductors

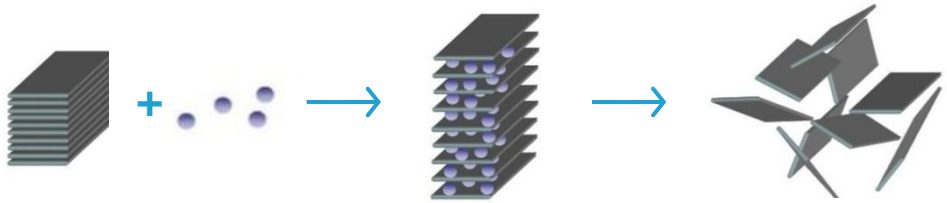
Max-Planck-Institut für Polymerforschung
Max Planck Institute for Polymer Research

“Graphene Is Not Graphene”

The Importance of Defining the Material



Graphene via Exfoliation of Graphite



Oxidation or Intercalation

Graphite Oxide Intercalated Graphite

Reduced Graphene Oxide Exfoliated Graphene

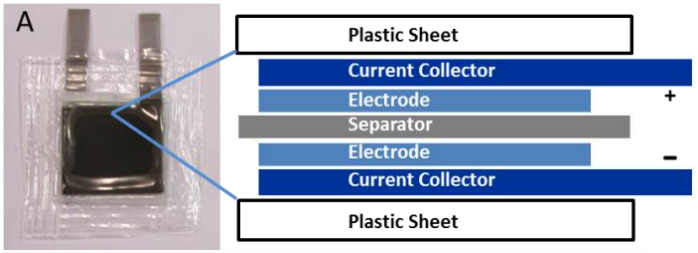
Schniepp, H. C. et al.; J. Phys. Chem. B **2006**, 110, 8535 -8539
Source: Ahmed Abdala

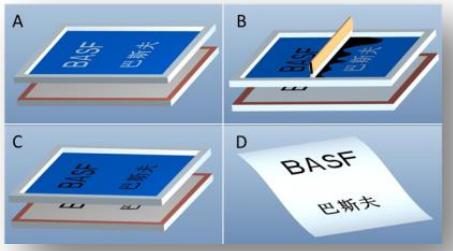
Graphene’s Competitors

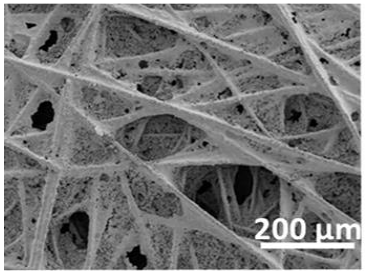
- Carbon Black, Graphite, Activated Carbon
- Large-volume commodities
- Typical price range 1 – 10 $/kg

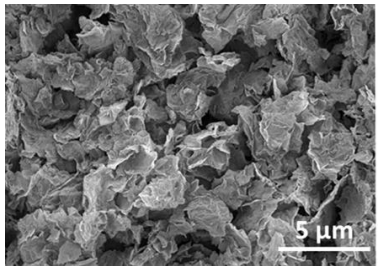
Recent Research Highlights from BASF

- Printable energy storage devices
- Increased printing speed of 0.1 sec/electrode
- Capacity 269 F g^{-1}, Energy Density 9.3 Wh kg^{-1} (1M H_2SO_4)









Y. Xu, M. G. Schwab, A. J. Strudwick, I. Hennig, X. Feng, Z. Wu, K. Müllen *Adv. Energy Mater.* 3, 1035–1040 (**2013**)
Y. Xu, I. Hennig, D. Freyberg, A. J. Strudwick, M. G. Schwab, T. Weitz, K. C. Cha *J. Power Sources* 248, 483 (**2014**)

Various Approaches of Making Si Anode Materials Employing Carbon & Graphene

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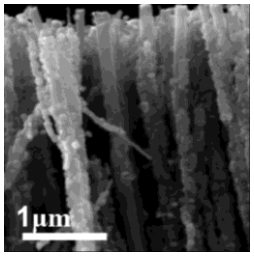
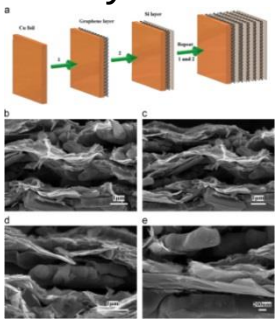
Si LIB Anode

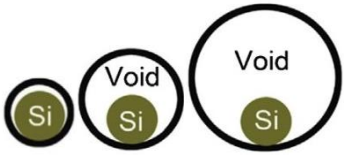
Si coating of C



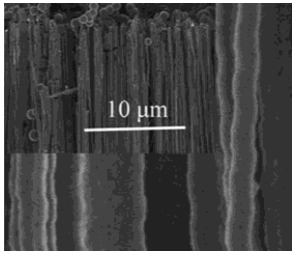
Si-Graphene multilayer coating



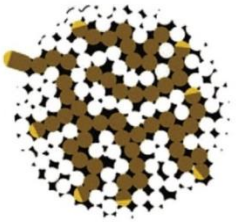
Core / Shell



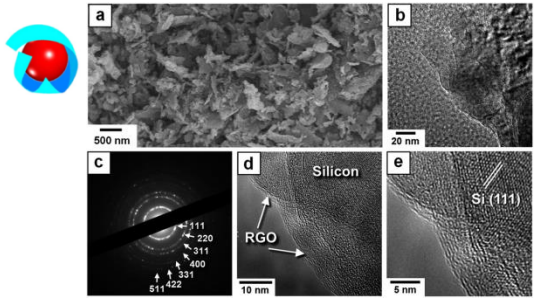
C coating of Si



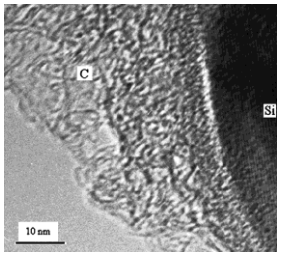
Porous Si-C



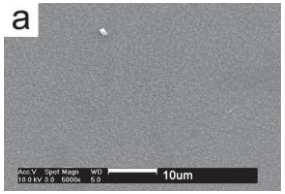
Graphene encapsulation of Si



Si & C or Graphene mixing by milling or pyrolysis



Si thin film



The Future Role of Carbon

Solving New Technical Challenges

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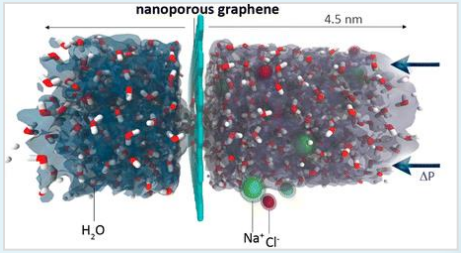
Today's Trend: Synergies with combinations of new and established materials

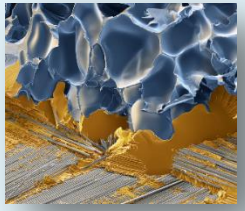
Future Trends: Creating Hybrid Materials (Contribution by Prof. K. Müllen)

Carbon for efficient water and air purification membranes



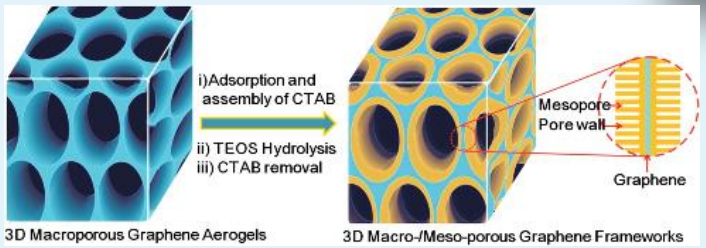
DOI: 10.1021/nl3012853

Lightweight composites



Energy Storage and Mobile Technologies

New supercapacitor technologies with hybrid structures



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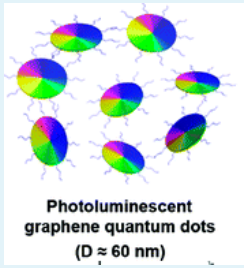

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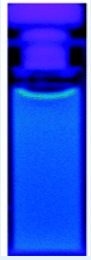

Prof. Müllen in the Academic Space

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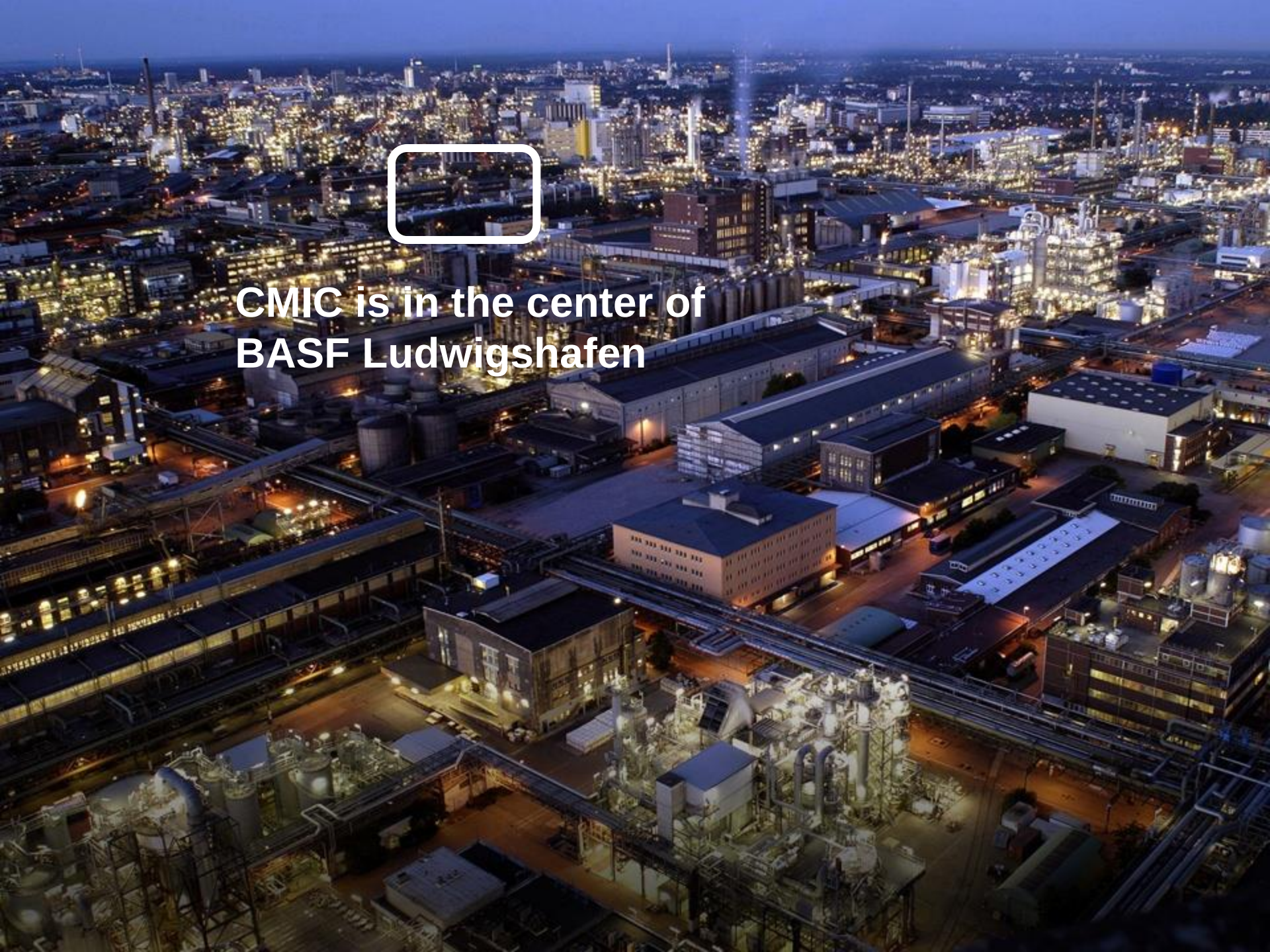
Graphenes as potential material for electronics | Atomically precise bottom-up fabrication of graphene nanoribbons | Large single-molecule fluorescence enhancements produced by a bowtie nanoantenna | Nitrogen-Doped Ordered Mesoporous Graphitic Arrays with High Electrocatalytic Activity for Oxygen Reduction | Transparent carbon films as electrodes in organic solar cells | Fabrication of Graphene-Encapsulated Oxide Nanoparticles: Towards High-Performance Anode Materials for Lithium Storage | Two-dimensional graphene nanoribbons | Composites of Graphene with Large Aromatic Molecules | Field-effect transistors based on a benzothiadiazole-cyclopentadithiophene copolymer | Dispersion of Graphene Sheets in Organic Solvent Supported by Ionic Interactions | Ultrahigh Mobility in Polymer Field-Effect Transistors by Design | Polyphenylene-Based Materials for Organic Photovoltaics | Towards high charge-carrier mobilities by rational design of the shape and periphery of discotics | The Influence of Morphology on High-Performance Polymer Field-Effect Transistors | Graphene-Based Carbon Nitride Nanosheets as Efficient Metal-Free Electrocatalysts for Oxygen Reduction Reactions | Ladder-type pentaphenylenes and their polymers: Efficient blue-light emitters and electron-accepting materials via a common intermediate | Pyrene-Based Materials for Organic Electronics | Graphene-Based Nanosheets with a Sandwich Structure | Patterned Graphene Electrodes from Solution-Processed Graphite Oxide Films for Organic Field-Effect Transistors | 3D Nitrogen-Doped Graphene Aerogel-Supported Fe3O4 Nanoparticles as Efficient Eletrocatalysts for the Oxygen Reduction Reaction | Graphene as Transparent Electrode Material for Organic Electronics | Nanographene-Constructed Hollow Carbon Spheres and Their Favorable Electroactivity with Respect to Lithium Storage | Intramolecular charge-transfer tuning of perylenes: Spectroscopic features and performance in Dye-sensitized solar cells | Dithieno[2,3-d;2′,3′-d′]benzo[1,2-b;4,5-b′]dithiophene (DTBDT) as Semiconductor for High-Performance, Solution-Processed Organic Field-Effect Transistors | Sandwich-Like, Graphene-Based Titania Nanosheets with High Surface Area for Fast Lithium Storage | A bottom-up approach from molecular nanographenes to unconventional carbon materials | High thermal stability and rigid rod of novel organosoluble polyimides and polyamides based on bulky and noncoplanar naphthalene-biphenyldiamine | The Rylene Colorant Family-Tailored Nanoemitters for Photonics Research and Applications | Synthesis and self-organization of core-extended perylene tetracarboxdiimides with branched alkyl substituents | Porous graphenes: two-dimensional polymer synthesis with atomic precision | Liquid Crystalline Ordering and Charge Transport in Semiconducting Materials | An Improved Perylene Sensitizer for Solar Cell Applications | Self-assembly of periodic bicomponent wires and ribbons | Epitaxial composite layers of electron donors and acceptors from very large polycyclic aromatic hydrocarbons | Nanographenes as active components of single-molecule electronics and how a scanning tunneling microscope puts [illegible] Structure-Property Relationships in Dithienosilole-Benzothiadiazole Donor-Acceptor Copolymers | Blue-green up-conversion: Noncoherent excitation by NIR light | A one-step approach towards carbon-encapsulated hollow [illegible] in lithium batteries | Polyphenylene-type emissive materials: Poly(para-phenylene)s, polyfluorenes, and ladder polymers | Revealing competitive Forster-type resonance energy-transfer pathways in single bichromophoric [illegible] on bridged phenylenes as electronic materials | Catalyst-free Preparation of Melamine-Based Microporous Polymer Networks through Schiff Base Chemistry | Probing intramolecular Forster resonance energy transfer [illegible] diimide-based dendrimer by ensemble and single-molecule fluorescence spectroscopy | Improving polymer transistor performance via morphology control | Molecular clusters in two-dimensional surface-confined nan[illegible]d dynamics | A Germanium-Carbon Nanocomposite Material for Lithium Batteries | Probing conformational dynamics in single donor-acceptor synthetic molecules by means of photoinduced reversible electron t[illegible]con/metal and carbon/metal oxide nanocomposites | Three-Dimensional Nitrogen and Boron Co-doped Graphene for High-Performance All-Solid-State Supercapacitors | Ladder-type pentaphenylene dyes fo[illegible]nd UV Photoreduction of Graphene-Polyoxometalate Composite Films for Electronics | From industrial colorants to single photon sources and biolabels: The fascination and function of rylene dyes | Relat[illegible]bility of branched alkyl hexa-peri-hexabenzocoronenes | A new photostable terrylene diimide dye for applications in single molecule studies and membrane labeling | Efficient Synthesis of Heteroatom (N[illegible]-Porous Silica Sheets for Oxygen Reduction Reactions | Bottom-Up Fabrication of Photoluminescent Graphene Quantum Dots with Uniform Morphology | Mesitylboron-substituted ladder-type pentaphe[illegible]ng properties | Three-Dimensional Graphene-Based Macro- and Mesoporous Frameworks for High-Performance Electrochemical Capacitive Energy Storage | Direct Access to Metal or Metal Oxide Na[illegible]s for Electrochemical Energy Storage | Photovoltaic charge generation visualized at the nanoscale: A proof of principle | Synthesis and applications of core-enlarged perylene dyes | A hexa-peri-hexabe[illegible]ar electronics | Transparent, Thermally Stable and Mechanically Robust Superhydrophobic Surfaces Made from Porous Silica Capsules | Surface-assisted cyclodehydrogenation provides a synthetic ro[illegible]henes | Tuning the Columnar Organization of Discotic Polycyclic Aromatic Hydrocarbons | Electronic excitation energy transfer between two single molecules embedded in a polymer host | Two-Dime[illegible]Precursor Mobility and Reactivity | Large polycyclic aromatic hydrocarbons: Synthesis and discotic organization | Graphene Nanoribbons by Chemists: Nanometer-Sized, Soluble, and Defect-Free | N[illegible]nductor at surfaces: Long-range mass transport forming giant functional fibers | Exciton fission and fusion in bis(tetracene) molecules with different covalent linker structures | Energy and electron trans[illegible]From armchair to zigzag peripheries in nanographenes | Controlled Self-Assembly of C-3-Symmetric Hexa-peri-hexabenzocoronenes with Alternating Hydrophilic and Hydrophobic Substituents in Solu[illegible]romatic hydrocarbons | Porous Graphene as an Atmospheric Nanofilter | From Nanographene and Graphene Nanoribbons to Graphene Sheets: Chemical Synthesis | Charge-Carrier Transporting Gra[illegible]on Highly Ordered Single Polymer Fibers | Rational Optimization of Benzo[2,1-b;3,4-b′]dithiophene-Containing Polymers for Organic Field-Effect Transistors | Design strategies for organic semicon[illegible]hiophene Dendrimers with a Hexa-peri-hexabenzocoronene Core-Synthesis, Characterization and Performance in Bulk Heterojunction Solar Cells | Self-Assembly of a Donor-Acceptor Dyad Across [illegible]ic Electronics | Self-assembly of positively charged discotic PAHs: From nanofibers to nanotubes | Polyoxometalate assisted photoreduction of graphene oxide and its nanocomposite formation | Reinf[illegible]y hydrogen bonds: From microscopic aggregates to macroscopic fluorescent organogels | Pyrene as chromophore and electrophore: Encapsulation in a rigid polyphenylene shell | Blue-emitting carbon- and[illegible]Visualizing and controlling vibrational wave packets of single molecules | Water-soluble monofunctional perylene and terrylene dyes: Powerful labels for single-enzyme tracking | A conjugated polycarbazole ring[illegible]Hopping in Single Molecular Junctions by Measuring Length and Temperature Dependence | Controllable Growth and Field-Effect Property of Monolayer to Multilayer Microstripes of an Organic Semiconductor | Explo[illegible]ng with ultrastable perylene dyes | Diffusion of oriented single molecules with switchable mobility in networks of long unidimensional nanochannels | Vapor sorption and electrical response of Au-nanoparticle-dendrimer com[illegible]oscale Architecture and Function in Photovoltaic Multichromophoric Arrays as Visualized by Kelvin Probe Force Microscopy | Benzo[1,2-b : 4,5-b′]bis[b]benzothiophene as solution processible organic semiconductor for field-e[illegible]erojunction photovoltaics based on alkyl substituted discotics | The Effect of Solvent Additives on Morphology and Excited-State Dynamics in PCPDTBT:PCBM Photovoltaic Blends | Solution Processable Fluorenyl Hexa-peri-hexaben[illegible]ield-Effect Transistors and Solar Cells | Synthesis of Microporous Carbon Nanofibers and Nanotubes from Conjugated Polymer Network and Evaluation in Electrochemical Capacitor | Polypyrene Dendrimers | Arylamine-substituted oligo(ladder-type[illegible]phenylene)s: Electronic communication between bridged redox centers | Novel core-expanded rylenebis(dicarboximide) dyes bearing pentacene units: Facile synthesis and photophysical properties | From ambi- to unipolar behavior in discotic dye field-effect transistors | Polytriphenylene Dendrimers: A Unique Design for Blue-Light-Emitting Materials | One-dimensional porous carbon/platinum composites for nanoscale electrodes | Synthesis of conjugated polymer nanoparticles in non-aqueous emulsions | Virus-like Particles Templated by DNA Micelles: A General Method for Loading Virus Nanocarriers | Poly(phenylene-pyridyl) dendrimers: Synthesis and templating of metal nanoparticles | Helical packing of discotic hexaphenyl hexa-peri-hexabenzocoronenes: Theory and experiment | A Divergent Synthesis of Very Large Polyphenylene Dendrimers with Iridium(III) Cores: Molecular Size Effect on the Performance of Phosphorescent Organic Light-Emitting Diodes | Self-assembly, molecular dynamics, and kinetics of structure formation in dipole-functionalized discotic liquid crystals | Forever young: polycyclic aromatic hydrocarbons as model cases for structural and optical studies | Self-assembly of chiral molecular honeycomb networks on Au(111) | Electron-deficient N-heteroaromatic linkers for the elaboration of large, soluble polycyclic aromatic hydrocarbons and their use in the synthesis of some very large transition metal complexes | Helter-Skelter-Like Perylene Polyisocyanopeptides | Temperature-Enhanced Solvent Vapor Annealing of a C-3 Symmetric Hexa-peri-Hexabenzocoronene: Controlling the Self-Assembly from Nano- to Macroscale | Nitrogen-Doped Graphene and its Iron-Based Composite As Efficient Electrocatalysts for Oxygen Reduction Reaction | Detection of TNT explosives with a new fluorescent conjugated polycarbazole polymer | Transparent, highly conductive graphene electrodes from acetylene-assisted thermolysis of graphite oxide sheets and nanographene molecules | Cooperative Molecular Motion within a Self-Assembled Liquid-Crystalline Molecular Wire: The Case of a TEG-Substituted Perylenediimide Disc | Rainbow Perylene Monoimides: Easy Control of Optical Properties | 8-Quinolinolates as ligands for luminescent cyclometalated iridium complexes | Poly(2,7-phenanthrylene)s and poly(3,6-phenanthrylene)s as polyphenylene and poly(phenylenevinylene) analogues | Backbone Curvature in Polythiophenes | Synthesis, helical organization, and fibrous formation of C-3 symmetric methoxy-substituted discotic hexa-peri-hexabenzocoronene | Photophysical study of bay substituted perylenediimides | Polythiophene/Perylene Diimide Solar Cells - the Impact of Alkyl-Substitution on the Photovoltaic Performance | Core, Shell, and Surface-Optimized Dendrimers for Blue Light-Emitting Diodes | Electronic Transport Properties or Ensembles of Perylene-Substituted Poly-Isocyanopeptide Arrays | A polyphenylene dendrimer-detergent complex as a highly fluorescent probe for bioassays | Controlling single-molecule conductance through lateral coupling of pi orbitals | Diffusion in Polymer Solutions Studied by Fluorescence Correlation Spectroscopy | A simple approach towards one-dimensional mesoporous carbon with superior electrochemical capacitive activity | Self-assembly of perylene monoimide substituted hexa-peri-hexabenzoecoronenes: Dyads and triads at surfaces | Triangular Trinuclear Metal-N-4 Complexes with High Electrocatalytic Activity for Oxygen Reduction | Controllable Columnar Organization of Positively Charged Polycyclic Aromatic Hydrocarbons by Choice of Counterions | Defocused Wide-field Imaging Unravels Structural and Temporal Heterogeneity in Complex Systems | Blue-Emitting Poly(2,7-pyrenylene)s: Synthesis and Optical Properties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