Holland Chemistry

Global Challenges, Smart Solutions

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Holland Chemistry

Global Challenges, Smart Solutions

The Netherlands is one of the twenty largest economies in the world and is a leading global knowledge economy. Holland has a longstanding history of invention, moving around the oceans of the world, trading with other countries. In times of global, social and economic challenges, the Dutch find ways of how innovation and entrepreneurship can continue to grow.

Holland Chemistry

The demand for clean energy, healthy nutrition, affordable healthcare and dry feet is global. The Netherlands has an excellent track record when it comes to finding solutions to these major issues. To come up with the optimal solutions, numerous different companies, research institutes, government bodies and civil society organisations in the Netherlands have joined forces in nine Top Sectors, one of which is **Holland Chemistry** (in Dutch: Topsector Chemie).

Green and sustainable solutions

In **Holland Chemistry**, companies, researchers and the Dutch government work together in public-private partnerships on **green and sustainable solutions** for the seven **Grand Societal Challenges** described in the European Commission's ambitious Horizon 2020 programme. **Holland Chemistry** focuses on five of those challenges: health, nutrition, energy, transport, and resources and the climate. In other words, it deals with issues such as sustainable products, renewable resources, clean production methods and smart materials.

World class chemistry

In terms of both science and industry, the Dutch chemical sector is one of the **very best in the world**. Through its **manufacturing activities**, the chemical sector contributes in a unique way towards moving the economy and society forward. The quality of its research is excellent, its products are innovative and of the highest grade, and the sector itself is highly competitive in terms of efficiency and effectiveness. With its turnover of over €56 billion, a workforce of 57,000 employees (8% of the total Dutch industrial workforce), an export value of €76 billion (comprising 18% of Dutch exports) and an R&D expenditure of €1 billion (23% of the total Dutch industrial R&D expenditure), the chemical sector is of enormous importance for the Netherlands[1].

Key role in circular economy

The chemical sector comprises a broad spectrum of subdisciplines of the chemical sciences that together are crucial for the innovative capacity and production of companies in many other sectors. With its bulk and specialty chemicals, the chemical sector is capable of making the most of raw materials for nutritional ingredients, medicines and innovative materials. Thanks to its position at the base of numerous different value chains, the chemical sector also plays a **key role**, along with other sectors such as energy and agri-food, in the transition towards a sustainable society with a circular economy.

Holland Chemistry's ambitions

Holland Chemistry has set for itself the following three ambitious goals:

- By 2050, the Netherlands will rank the highest in the world when it comes to **green and sustainable chemistry**.
- By 2050, the Netherlands will be in the global top 3 of producers of **smart materials** with a high added value and **smart solutions**.
- Thanks to **high-quality, ground-breaking scientific research** in the Netherlands new areas of science and innovation will open up.

Four main thrusts

To reach these goals, Holland Chemistry is stimulating innovation and collaboration between companies and knowledge institutions by way of four main thrusts:

- **Chemistry of Advanced Materials**
- **Chemistry of Life**
- **Chemical Conversion, Process Technology & Synthesis**
- **Chemical Nanotechnology & Devices**

These thrusts are based on societal challenges, industrial strengths and the scientific knowledge base. These are areas in which the Netherlands makes the difference, in which innovations can produce valuable new products, and in which a contribution can be made to various (international) societal challenges.

A roadmap for each thrust

For each of the four main thrusts, Holland Chemistry has drawn up a separate roadmap. To successfully deal with the subjects mentioned in these roadmaps, enabling sciences and technologies such as modelling, computational chemistry and spectroscopy, complexity, chemometrics and analytical chemistry are naturally of great importance.

Holland Chemistry distinguishes two important cross-sectoral priorities: biobased economy (BBE) and resource efficiency, both of which have been integrated within the four roadmaps.

The chemical sector is an important enabler for numerous other industries and sectors. Multidisciplinary and cross-sectoral collaboration as well as collaboration within and across the knowledge chain and the chains of suppliers, producers and users are part of the very essence of the chemical sector. Each of the roadmaps of Holland Chemistry goes into detail regarding these types of collaboration.

[1] Facts and figures about the Dutch chemical industry from 2014 (see www.vnci.nl).

Executive Summary of the **"Chemistry of Advanced Materials"** Roadmap

Artificial materials are the cornerstone of our global society. Progress in the field of materials chemistry has enabled numerous new technologies and applications ever since the Stone Age, and will continue to do so in the coming decades. The Netherlands has a very strong position in various fields of advanced materials, and has a high ambition level for extending on this position; in the period 2030-2040, The Netherlands will have settled its name globally as "rational material design" technology provider for high value-added materials and clean energy materials. In keeping with this long-term ambition level, the emphasis of materials chemistry research on the short term should be on mechanistic insight to be obtained for each of a plethora of desired functionalities and on the medium to long term on moving from increasing insight and understanding towards rational material design capabilities. For the latter, a broader scientific foundation of functionality of materials should be developed, including (predictive) modelling of formulations and properties.

The roadmap Chemistry of Advanced Materials has focused on three tasks: Materials with added Functionality, Thin films and Coatings, and Materials for Sustainability. All three tasks revolve around the key word "functionality" and prepare for a future in which advanced materials exert new functions, new combinations of functions, or true step-change improvements in their functions. Under the first task, the functionality is defined by the continuum (or "bulk") intrinsic properties of the materials, whereas surface effects dominate those properties under the second task. Under the third task, the functionality is related to sustainability. Either directly, when the material itself is made in a sustainable way, or indirectly, when the material enables sustainable energy harvesting or energy storage, reduction of energy consumption or requiring less (scarce) resources for production. Intrinsic design of advanced materials based on or allowing for circular economy or replacement of advanced materials with more sustainable alternatives is bridging task 3 with tasks 1 and 2. Of course, these three tasks are not mutually exclusive.

The overall ambitions of each task and the specific steps that should be taken between now and 2040 are summarized in the table below.

This roadmap on the Chemistry of Advanced Materials is mainly sustained by the Top sector Chemistry roadmap on Making Sustainable Chemical Products and the cross sectorial platform for Biobased Economy, by providing sustainable raw materials and (catalytic) technology for control of conversion of these raw materials into advanced materials. This connects to the EU Horizon 2020 theme of Resource Efficiency. In turn, the major beneficiaries of this roadmap are in the Top sector Chemistry roadmaps on Chemistry of Life (Biomedical Materials) and on Nanotechnology and Devices, as well as in the top sectors High-Tech Systems and Materials, Energy and Water for applications of these advanced materials. These applications are fully in line with the EU Horizon 2020 themes Health, Energy, Transport, and Nutrition Security.

	Short Term Now - 2020	Medium Term 2020 - 2030	Long Term 2030 - 2040	Program Line Ambition
Materials with Added Functionality	• Improved performance of existing materials. • Development self-healing polymers and ceramics. • Mechanistic insight for functional polymers, nanocomposites, metals, high tech materials.	• Higher strength polymers industrially produced • Rational material design capabilities. • Knowledge base for start-ups future materials, e.g. biomedical and self-healing.	• Reinforced composites and multi-functional materials successful in market. • High tech materials proven in prototypes for automotive and home. • Biomedical materials in clinical trials.	NL will have settled its name as "rational material design" technology provider for high value-added functional materials and clean energy materials.
Thin Films and Coatings	• New corrosion protection technologies for automotive, construction and Hi-Tech. • Coatings with anti-microbial properties. • Sensoring response coatings Self-healing technologies for thin films and membranes.	• First responsive and active coatings industrially produced. • Development of nanolayer production technologies. • Growth of start-up companies in areas like specialty coatings, ion/molecule sensing and air/water purification.	• Bio-interactive coatings industrially produced. • Implementation of nanolayer production technologies. • New energy creation concepts developed to prototypes.	NL will be a world leader in thin film technology and provide high value-added functional coatings, protective coatings and membranes combining sensory functions with separation technology.
Materials for Sustainability	• Predict and design circular material streams, start-ups. • Improved control molecular architecture of polymerisations with lower energy input. • Design of novel materials for energy harvesting and storage.	• New technologies for material replacement, reduction, reclaim and reuse. • Dedicated polymer additives for biobased polymers.	• Implement energy production and storage solutions in industrial commercial context. • Multifunctional (bio) catalysts for effective recycling. • Use of green solvent	NL will be leading as technology provider for circular use of high value (functional) materials, bio-based materials, and sustainable energy materials.
Enabling Science/ Technology	• Electrochemistry and research on energy storage (batteries) • Basic research in emerging classes of advanced materials. • Initiatives like Nano-NextNL Large scale infrastructure	• Modelling and computational chemistry on different length scales. • Material surface analysis and characterization of thin films (microscopy, spectroscopy, scattering, ellipsometry).	• Integration of multiple length scales. Understanding of how functional properties • on the nanoscale translate to functionalities on larger length scales, leading to implementation in new products.	

Executive Summary of the **“Chemistry of Life”** Roadmap

Understanding of Life on a molecular level (Chemistry of Life) provides a key that unlocks unlimited opportunities for breakthrough innovations, needed to address our global challenges for people today, and generations to come. The unifying aim in Chemistry of Life is therefore to bring about the chemical means and molecular understanding leading to an improved (precise), more and more personalized healthcare as well as more sustainable and healthy food for the benefit of mankind.

Our life is dependent on molecules that enable, regulate, improve or threaten Life. During the past century scientific breakthroughs led to the identification of molecules which are building blocks of life. We understand better and better their functions, how they interact with small molecules and how they contribute to life. This fundamental understanding is applied today in industry to develop products creating a better life for individuals and society as a whole. While progress was enormous, leading to novel and targeted medicine and securing our food supply for a growing population, we still face major gaps in understanding life on a molecular level, and we are still faced with great challenges in healthcare as well as a sustainable healthy food supply.

What are the next scientific breakthroughs in Chemistry of Life? How can The Netherlands contribute to these by using and further developing our excellent knowledge infrastructure and network of world class Universities, Knowledge Institutes and the private sector? How can we capture innovations and economic growth in The Netherlands based on these breakthroughs (e.g. expanding current vibrant biotech start-ups and establishing novel ventures)?

The answers will come from **collaborations**. Collaborations across disciplines, across industries (value chains), and across the world. The Chemistry of Life roadmap is therefore set up with a focus on molecular insights reaching out to (collaborating with) all sectors contributing to the scientific and economic breakthroughs the top sector wants to enable.

A three-pillar (task) roadmap has been developed to address the scientific challenges and economic opportunities in healthcare (task 1) and food/nutrition (task 2) and the link between them, connecting health and food/nutrition.

The **first pillar** (task 1) focuses on ‘Molecular entities, devices and approaches for understanding, monitoring and improving **personalized health**’.
Various human diseases are the result of altered or malfunctioning molecular/cellular mechanisms or genetic mutations. It is of utmost importance to understand the cellular wiring of the diseased state and develop (therapeutic) approaches to prevent this or reprogram and revert cells to a normal healthy state or to trigger cell death (apoptosis). Genomics, transcriptomics, proteomics, metabolomics data (omics, or panomics when integrated) from patient material, including the gut microbiota, constitute a treasure trove to understand and redirect molecular pathways. These pathways may be targeted by existing or newly developed drugs, thereby offering an avenue towards personalized medicine.
The **second pillar** (task 2) focuses on ‘Molecular entities, devices and approaches for understanding, monitoring and improving **food security**’. Unraveling the precise mechanisms that govern molecular interactions is at the very heart of Chemistry of Life. The Netherlands has always been a stronghold with respect to recognizing the importance of the interaction of chemistry and chemical biology in the life science sector. Such a molecular understanding will also enable the food sector to get to the next level answering fundamental scientific questions to provide breakthrough innovations that address societal needs related to food quality and security throughout the whole lifespan.
The **third pillar** (task 3) creates a deeper **understanding of the building blocks of life** and developing **enabling technologies** while providing valuable input for understanding, monitoring and improving health and food security.

	Short term Now-2020	Mid term 2020-2030	Long term 2030-2040	Programme Line ambition
Molecular entities, devices and approaches for understanding, monitoring and improving personalized health	• Personalized panomic analysis • Multidisciplinary multi-center of Drug Discovery • Understanding material properties contributing to improved compatibility in human cells.	• Target identification for (multifactorial) diseases • Structural information on the interaction of NCEs and bio- conjugates with target proteins • Explore new functionalities of Materials in human bodies (e.g. stability, release, mechanical strength, lubrication, antimicrobial).	• Development of novel clinically affordable disease-oriented workflows and devices • Development of NCEs and bio-conjugates for use in diagnostics, in vivo imaging, and clinical applications • Piloting and commercialization of new materials and devices	Improved and more affordable personalized health
Molecular entities, technologies and approaches for understanding, monitoring and improving food (security)	• Molecular understanding of factors impacting texture/ taste • Validated biomarkers of health and disease in order to come from descriptive models to predictive models • Identification of new, sustainable sources for protein supply	• Novel enzymes/microbes that tailor texture/taste both in situ and ex-situ • Quantitative and mechanistic models of in vitro and in vivo digestion of foods based on biochemical properties of food constituents • Novel biochemical processes for obtaining ingredients with reduced environmental footprint	• New, biochemically derived health promoting substances, including enzymes and micro-organisms • Correlation of in vitro and in vivo models • Novel ingredients to replace current, undesired food additives that are used to reduce spoilage	Improved and more sustainable food
Enabling technologies and approaches for fundamental understanding, monitoring and improving molecular entities in the Chemistry of Life	• Insight in the impact of the heterogeneity of proteins and protein complexes on cellular networks • Multidisciplinary center of Synthetic biology • Long term Public Private Partnership Programme on Building Blocks of Life	• Influence of heterogeneity in the dynamics of bio molecular networks and on the robustness of systems • Minimal cells that conduct specific biochemical reactions in a robust manner and that can be used in industrial applications related to bioenergy, biomaterials, chemical production	• Utilize the knowledge on network dynamics and cellular heterogeneity to tackle main societal challenges • Synthetic cell that in a controlled manner carries out basic biochemical reactions and that can replicate • “Organ-on-a-Chip” modules that can be used as a disease specific screening platform	Accurate cell systems for medical and energy applications

Executive Summary of the "Chemical Conversion, Process Technology & Synthesis" Roadmap

Making Sustainable Chemical Products
The roadmap of the program council "Chemical Conversion, Process Technology and Synthesis" addresses the grand challenge to transform our fossil-resource dependent economy into a low- carbon society that fully relies on sustainable and abundant resources. Innovations and breakthroughs in catalysis and process technology are recognized as key enabling technologies. The anticipated transition involves a three-pronged approach. Step **improvements in the efficiency** of current chemical process are needed to decrease energy and raw material consumption. In the short term, **new sustainable resources** such as biomass for the manufacture of chemical products will require new combinations of designer catalysis and advanced process technology, in fields such as C1-chemistry, waste recycling, and novel processes for the separation, purification and conversion of biomass.

Integration of renewable energy in the form of electricity is a medium term challenge to enable the desired long-term transition to a circular economy in which materials and CO_2 recycle are key elements. **Synthesis routes for complex functional molecules** need to be developed that allow sustainable production of any functional chemical product in a minimum of process steps and with 100% efficiency.

The desired breakthroughs that will drive these innovations require investments in fundamental science and technology. New spectroscopic tools will provide insight at molecular level, which will be combined with theory-based rational design of chemical processes and catalysts for the conversion and storage of energy, as well as for the synthesis of sustainable chemical products and materials. This will eventually lead to complete control over chemical process design and operation from atomic scale all the way up to reactor scale.

In order to reach the goals described in this roadmap, it will be necessary to invest in a concerted effort of considerable magnitude, for instance an **Advanced Research Center (ARC)** targeting chemical building blocks in the area of Catalysis, Process Technology and Synthesis, with a maximum impact for cooperating private and academic partners, and with international reputation. At the same time we should connect with regional initiatives. The envisioned scope would be a program of about 14 million euros per year for a period of ten years.

Overall Ambition: **To make the transition from our fossil resource dependent economy to a circular low-carbon economy that relies on sustainable and abundant resources.**

	Short Term Now - 2020	Medium Term 2020 - 2030	Long Term 2030 - 2040	Program Line Ambition
Making Molecules Efficiently	• Improved efficiency of current chemical processes • Novel C1 chemical processes	• Increasing use of renewable electricity in the chemical industry • Transition to biomass as source for chemicals	• Transition to solar as main energy resource • Biomass and CO_2 as main carbon source	Transition to a low-carbon economy
Making Molecules From Biomass	• Thermo-Chemical conversion of biomass • Demo-scale biorefinery based on 2nd generation sugars	• Process Intensification • Novel carbon efficient processes and products • Industrial biotechnological conversions	• Full scale biorefinery • Efficient purification/ separation routes for products of bio-origin	Discovering new routes for making chemicals in a truly sustainable way
Making Functional Molecules	• Catalyst design tools to control properties of polymeric materials. • Evolution of sustainable synthetic methodologies and catalysts. • Mechanistic advances in the synthesis of complex functional molecules.	• Low-cost, catalytic alternatives for radical polymerizations • Rational synthesis design for complex functional molecules • Improved process technology solutions	• Sustainable manufacturing of polymeric materials ba-sed on designer catalysts • Sustainable manufacturing of any funtional molecule with 100% efficiency	Reducing the ecological footprint of production, introducing novel chemical products with advanced properties and functionality
Enabling Science/ Technology	• New spectroscopic tools/ modeling methods to study reactions at molecular level • Integrated catalysis/ reactor technology design approaches	• Process intensification • Electrochemistry and electrocatalysis	• Rational design for chemical processes for energy conversion, storage and molecule and materials synthesis	Complete control over chemical process design and operation from atomic to reactor scale

Executive Summary of the "Chemical Nanotechnology & Devices" Roadmap

Mimicking, Measuring & Sensing, key in creating an ultimate insight into Bio & Synthetic (inter & intra) molecular processes

The roadmap "Chemical Nanotechnologies & Devices" refers to technologies and devices able to mimic, measure and sense (bio) chemical processes and is as such of crucial importance for the majority of the top sectors (Water, Life Sciences and Health, Agriculture & Food, Energy), and the top sector Chemistry in particular. From a technological point of view and envisioning a society in 2040, having free access to "personalized diagnostic sensors", the "factory of the future" and "sunlight as primary energy source", extensive technological breakthroughs in chemical, spatial (sub nm length scales) and temporal resolution are regarded vital. In this roadmap, a focused and prioritized program comprising (bio)sensors, micro/nanofluidics, flow-(micro) reactors, analytical technologies with ultimate (chemical, spatial & temporal) resolution and the third generation solar cells is described. These technologies are an integral part of the three main tasks, **Well-being**, **Cradle to Cradle 2.0** and **Energy**, which are highly related to "**People**, **Planet** & **Profit**".

	Short Term Now - 2020	Medium Term 2020 - 2030	Long Term 2030 - 2040
Well-being **3.1.1 Bio-active sensing and actuation devices**	• In the lab • Avoid adverse reactions • Single analytediagnostics	• On the body / near the person • Bio-mimetic devices • Panel of analytes • Early diagnostics/monitoring	• In the body • Bio-controlling devices • Comprehensive biochemical profile • Precision medicine • Closed-loop monitoring and treatment
3.1.2 Human model systems on a chip	• Biomembrane on chip • Organ(elle) on chip (liver, heart, lung, etc.) • Cell on chip • Multicellular system on chip	• Organ functionality on a chip • Combination of organs • Interacting organs -- mimic complex	• Body function • High throughput screening technology
3.1.3 Microfluidic devices for synthesis and formulations in medicine and food	• Existing active ingredients and targeting formulations and encapsulates	• New active ingredients and formulations concepts • Biologics by cascade reactions	• Integrated and flexible production of formulated drugs-custom-made rational-designed nanomedicines
Cradle to Cradle **3.2.1 Resource Efficiency and closed value added chains (gate-to-gate) material and energy flows**	High efficient and sustainable (bio) catalyst embedded in flow-reactors.	Proof of concept for low energy, resource efficient and waste less chemical flow process, including up-stream and downstream processing, towards final product	Operational "Factory of the Future" on basis efficient use of energy and resources, without waste-streams lacking economic value
3.2.2 Time To market, speed-up of the process development	Novel multi-model analytical technologies with ultimate chemical resolution, at lowest possible length and different time scales	Availability of innovative micro-flow reactor technologies for gas-, liquid- and solid-phase chemistry. Advances in molecular, process modelling and statistics	Implementation of the "factory of the Future" on basis of "flow chemistry" in variety of chemical production processes
3.2.3 Process Reliability & Unification	Novel multi-model analytical technologies (integration of micro- and spectroscopic tools) for product characterization	Implementation of advanced computational methodologies for process modelling and advanced chemometrics supporting.	Reliable industrial production (implementation of PAT approach) of a large variety of smart and complex chemicals, materials, on basis of flow chemistry (3D printing), e.g. chemical modified (personalized) biopharmaceuticals, food application
Energy **3.3.1 Electro- chemical reduction of CO_2 with minimum over- potential**	• New technology for efficient electrochemical catalysis	• Solar catalysis (water splitting)	• Energy production and storage at point of use
3.3.2 Towards a third generation solar cell	• Development of new nanomaterials for solar cells	• Scalable synthesis routes • Scaling up of material production • Integrated in the material development process	• Solar cell device development and optimization

Roadmap Holland Chemistry

Chemistry of Advanced Materials

Task 1: Designing materials with the right functionality
- 1.1 Traditional materials [HTSM, Energy] ■
- 1.2 Multi-functional materials [HTSM, Energy, Creat. ■■
- 1.3 High-tech materials [HTSM, Energy, Creat. Ind.] ■■
- 1.4 Biomedical materials [LSH, HTSM] ■■■

Task 2: Thin films and coatings
- 2.1 Traditional coatings, packaging films, and membranes [Agri&Food, HTSM, Energy, Water] ■■
- 2.2 Multifunctional and responsive coatings and thin films [LSH, Agri&Food, HTSM, Water, Creat. Ind.] ■■
- 2.3 Bio-(inter)active sensors, coatings and films [LSH, HTSM] ■■
- 2.4 Coatings for energy creation/saving [Energy] ■

Task 3: Materials for sustainability
- 3.1 Replacement of petrochemical feedstocks by bio-based feedstocks [BBE] ■
- 3.2 Improved waste management by recycling of materials, re-use and recovery of product components and / or compound [Agri&Food, BBE, HTSM, Creative Ind.] ■■
- 3.3 Sustainable materials for energy [BBE, Energy] ■■

Chemistry of Life

Task 1: Molecular entities, devices and approaches for understanding, monitoring and improving personalized health
- 1.1 Development of analytical and biophysical devices [LSH, HTSM, Agri&Food] ■
- 1.2 Creation of new chemical, molecular and cellular entities [LSH] ■■
- 1.3 Biomedical materials for improved functionalities ■

Task 2: Molecular entities, technologies and approaches for understanding, monitoring and improving food (security)
- 2.1 Biochemical tailoring of food [Agri&Food] ■■
- 2.2 Understanding food digestion and metabolism to increase nutritional availability and health [LSH, Agri&Food] ■■
- 2.3 Sustainable production and consumption [BBE, Agri&Food] ■■

Task 3: Enabling technologies and approaches for fundamental understanding, monitoring and improving molecular entities in the Chemistry of Life
- [LSH, Agri&Food, BBE, Energy] ■■

Chemical Conversation, Process Technology and Synthesis

Task 1: Making molecules efficiently
- 1.1 Feedstock diversification: C1 chemistry [Energy] ■
- 1.2 Feedstock diversification: sustainable resources, solar, wind and others [BBE, Energy] ■■
- 1.3 Efficiency in chemical production ■

Task 2: Making molecules from biomass
- 2.1 (Thermo-)chemical biomass conversion [BBE, Agri&Food, Energy]
- 2.2 Biomass conversion using industrial (white) biotechnology [BBE, Agri&Food, LSH, Energy] ■
- 2.3 Biorefining and circular economy [BBE, Agrii&Food, Energy, Water] ■■

Task 3: Making functional molecules
- 3.1 High performance materials [Energy] ■■
- 3.2 Speciality, pharma and fine chemicals [Agri&Food, LSH, HTSM] ■■
- 3.3 Process technology for manufacturing functional molecules [HTSM] ■■■

Chemical Nanotechnology and Devices

Task 1: Well-being (Quality of life)
- 1.1 Bio-active sensing and actuation devices [LSH, HTSM, Water] ■■
- 1.2 Human disease and organ model systems on a chip [LSH, Agri&Food, HTSM] ■
- 1.3 Microfluidic devices for synthesis and formulations in medicine and food [LSH, HTSM, Agri&Food] ■■

Task 2: Cradle to cradle 2.0
- 2.1 Resource efficiency and closed value added chains (gate to gate) material and energy flows [HTSM, Energy, BBE] ■
- 2.2 Time to market speed up of the process development [LSH, HTSM] ■■
- 2.3 Process reliability and unification [LSH, HTSM, Agri&Food] ■■

Task 3: Energy efficiency and storage
- 3.1 Electrochemical reduction of CO_2 with minimum over-potential [HTSM, Energy] ■■■
- 3.2 Towards a third generation solar cell [HTSM, Energy, BBE] ■

Crossover with other roadmaps:
- ■ *Link to Chemistry of Advanced Materials*
- ■ *Link to roadmap Chemistry of Life*
- ■ *Link to roadmap Chemical Conversion, Process Technology and Synthesis*
- ■ *Link to roadmap Chemical Nanotechnology and Devices*

Companies involved in PPPs within Holland Chemistry

20Med Therapeutics
3DPPM

A
Abundnz
Airborne
Akzo Nobel Chemicals
Akzo Nobel Industrial Chemicals
Albemarle Catalysts Company
Amsterdam Scientific Instruments
Apollo Vredestein
Aquastill
Arizona Chemicals
Arkema
ASMI
ASML Netherlands
Aspen Pharmacare
Avantium Technologies
Avantor Performance Materials
AVEBE
Avery Dennison

B
BaseClear
BASF Nederland
Bayer
Beckman Coulter Nederland
Beckman Coulter, Corporate Headquarters
Bender Analytical Holding
Bioclear
BioNovion
BioTools
Braskem

C
C4C Holding
Cambridge Major Laboratories
Cargill
ten Cate
ChemConnection
Chemtrix
Chemtura
Chiralix
Corbion Purac
Cosun
Cristal Therapeutics
Croda
Crossbeta Biosciences
Crucell
CytoBuoy

D
Danone
Da Vinci Europe Laboratory Solutions
DELMIC
Dionex Benelux
Dow Benelux
DSM Coating Resins
DSM Food Specialties
DSM Gist Services BV
DSM Innovative Synthesis
DSM R&D Solutions
DSM Resolve
DSM Resolve, Lifetec
Dupont
DutchSpace
Dyadic Nederland

E
Eastman
EFC
Elopak
Elson Technologies
Emultech
Enzypep
ETD&C
EuroProxima
Evorik
Excytex

F
Fokker
FrieslandCampina
Fuji Film
FutureChemistry

G
Galapagos
Generation of Change
Genmab
Geochem Research
Givaudan

H
HAL Allergy
Heineken Supply Chain
Heinz
Huntsman

I
ICL
INTEGREX Research
Ionicon Analytik

J
Johnson Matthey Catalysts

K
Katwijk Chemie
KNN
Krehalon

L
Lanxess
Latexfalt
Lionix
Lucite International UK

M
Maastricht Instruments
Magneto Chemie
Materiomics
MercaChem
Micronit Microfluidics
Mimetas
Momentive
MSD
MTSA

N
Naturalis Biodiversity Center
Nestlé
Netherlands Translational Research Center
Norit
NovioSmart
NovioTech
Nuplex
NXP

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Océ
Octoplus
Oerlemans Plastics
Okklo Life Sciences
Omics2Image

P
Pansynt
Paques
Pepscope
Pervatech
Philips Medical Systems
PPG

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SABIC
Sachem
Sasol
Scientific Computing & Modelling
Shell Global Solutions International
Shell Research and Technology Centre
Simadan
SKF
SoliQz
Solliance
SolSep
Solvay
SpinId/FlowID
Spinnovation Analytical
Stichting Waterproef
Surface Preparation Laboratory
Surfix
SyMo-Chem
Synbra
Syncom
Syngenta
Synthon

T
Tata Steel
Technex (with associated partner BioNavis)
Technobis
Technoforce
Teijin Aramid
TropIQ Health Sciences

U
UbiQ Bio
Unilever R&D Vlaardingen
U-Protein Express

V
VDL
VibSpec-Training
Voltea
van Wijhe

W
Waters Chromatography

Z
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