Energy Research at the Paul Scherrer Institut

72th Semi-Annual ETSAP Meeting, December 11, 2017
Main research areas (first- and third-party funding)

- Materials Research: 35%
- Life Sciences: 24%
- Particle Physics: 8%
- Nuclear Energy and Safety: 13%
- Energy and Environment: 20%

Paul Scherrer Institute - the Swiss National Lab

- Switzerland: Basel, Aarau/Bern, Zürich
- Germany: Germany

Facilities:
- Synchrotron light source
- Neutron source
- Proton therapy
- Proton accelerator
- Neutron source
- Solar concentrator
- Muon source
- Radio chemistry
- Radio pharmacy
- Biology
- Energy research
- Nanotechnology
- Hotlab
- SwissFEL
- PSI west
- PSI east
Neutrons – insights into fuel cells

Water balance of fuel cells is crucial

Neutron radiography of operating fuel cells

 Voltage [mV] vs. Average water content [a.u.]

Muons – less energy consuming electronic devices

Semiconductors and magnetism: materials for tomorrow’s information technology
Swiss Synchrotron Light Source SLS (operational since 2001)

SLS today: 1500 users per year
11% use by industry
500 publications per year

understanding materials for
• energy research
• information technology of tomorrow
• advanced manufacturing
• development of new drugs

“taking pictures”

Macromolecular crystallography beamlines – powerful tool for pharmacological research

Anders et al, Nature 2014
Brunner et al, Nature 2014
Chellamuthu et al, Cell 2014
Chowdhury et al, Nature 2014

Erzberger et al, Cell 2014
Fischer et al, Nature 2014
Hassaine et al, Nature 2014
Hennig et al, Nature 2014

Jinek et al, Science 2014
Lingaraju et al, Nature 2014
Meusch et al, Nature 2014
Perez-Vargas et al, Cell 2014

Schmalen et al, Cell 2014
Srinivasan et al, Science 2014
Steuber et al, Nature 2014
Wang et al, Nature 2014
Human Health

Structure of proteins for the targeted development of new drugs

Radio pharmaceuticals for the diagnosis and therapy of tumours

Proton therapy for
- destruction of tumours
- protection of healthy tissue

Protons – promising particles in cancer treatment

improved radiation therapy;
~ 200 patients/year
SwissFEL – a forefront research infrastructure for CH

**Synchrotron light**
- fine ($\lambda \geq 1\text{Å}$), slow (100 ps)

**Optical laser light**
- coarse ($\lambda \geq 200 \text{nm}$), fast ($\geq \text{fs}$)

**SwissFEL**
- fine ($\lambda \approx 1\text{Å}$) and fast (10 fs) at extremely high intensity

New, direct insights into physical, chemical and biological processes governing our everyday lives

- Nuclear Energy and Safety division (NES)

**Maintaining nuclear competence**

**Safety of nuclear reactors**
- Understanding relevant phenomena
  - Normal Operation
  - Severe Accidents
- Materials performance (barrier integrity)

**Waste Management**
- Multiscale reactive transport of radio-isotopes
- Safety of deep geological repository

- Education & Technology Monitoring
  - Reduced risk = Reduced waste
Decommissioning
– Activation analysis, radiation protection issues, conditioning and intermediate storage, related topics
– Competence towards remediation

Radioactive Material Handling and Analysis
– Maintaining the capability of handling and fostering scientific analysis of radioactive materials in the Hot Laboratory (AHL)
– Contributing towards better understanding of nuclear materials behavior (in service degradation / ageing)
– Participation to the development and analysis of new materials for nuclear installation (reactor, neutron sources, accelerators)
– Generating data for validation of codes
– Engagement in basic research, in particular characterization at SLS and SINQ

Energy Systems Analysis

<table>
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<tr>
<th>Laboratory for Energy Systems Analysis (LEA)</th>
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<td>S. Hirschberg (until April 2017) / Vinh Dang</td>
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<th>Technology Assessment (TA)</th>
<th>Energy Economics (EE)</th>
<th>Risk &amp; Human Reliability (RHR)</th>
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<tr>
<td>P. Burgherr</td>
<td>T. Kober</td>
<td>V. Dang</td>
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• Understanding and comparisons of current energy technologies and future energy options for the electricity, heating and transport sectors based on environmental, economic & socially relevant factors.
• Quantitative, systematic, and interdisciplinary assessments of energy technologies and energy supply strategies (methodological frameworks and databases).
• Supporting rational decision-making for sustainable development in the Swiss and international energy sectors
• Communicating balanced research findings to decision-makers and stakeholders.

• Understanding of energy technology development
• Combining high level of technology detail with Systems approach for co-evolution of energy provision, conversion, transmission, distribution, end-use.
• Identifying policy strategies for the realization of sustainable energy systems at Swiss and global levels.
• Developing and analyzing scenarios of future energy system development and technology change using detailed energy-system models.
• Working with European Commission, World Energy Council, Swiss Federal Office of Energy and others

• Advanced methods for Human Reliability Analysis (HRA); analysis of human performance data
• Tools and approaches for simulation-based safety analysis
• Probabilistic Safety Assessment (PSA)
• Analysis of human performance in relation to risk assessment of safety-critical systems
• Accident scenario dynamics, including uncertainties
• Adaptation and application of PSA and risk analysis methods in other domains beyond nuclear energy
• Supporting the Swiss Federal Nuclear Safety Inspectorate (ENSI) in the safety analyses of the Swiss Nuclear Power Plants.
Switzerland needs to tackle two major challenges:

- Replacement of potentially dangerous nuclear energy (decision of Federal Council to phase-out nuclear power)
- Reduction of CO$_2$ emissions

→ Electricity gap needs to be closed

- Cap consumption at 60 TWh
- Increase energy efficiency (saving)
- Maximize hydropower (37 → 40 TWh)
- Increase renewables (1.3 → 22 TWh)
- Complement with fossil fuel production

Strengthen Energy Research
Role model of public sector
International cooperation
Phase 2: ecological tax reform
Options for Integrating Decentralized Energy

1. Electricity storage for later use
2. Controlling and temporally shifting consumption
3. Conversion of electricity to chemical energy forms

Storage is key enabling technology for the integration of intermittent renewable energies.
Division Energy and Environment at a Glance

Technical biomass valorization
- Stroh (straw)
- Holz (wood)
- Algen (algae)
- Gras (grass)

Electrolysis with PV Electricity

Energy Systems Analysis

ESI-Platform

Methane CH₄

Environmental relevance

Thermal Processes and Combustion

Electrochemistry, Fuel Cells

Swiss Competence Center for Energy Storage

Battery

Heat

Integration

H₂

Hydrogen

CH₄

Synthetic Fuels

www.sccer-hae.ch

Prof. Dr. Thomas J. Schmidt
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Combining Electrolyzers with Efficient Fuel Cells

- **2004**
  - 30 kW FC
  - 1.4 kg/kW
  - Development with Michelin

- **2011**
  - 30 kW FC
  - Development with Belenos Clean Power

- **2016**
  - 63 kW FC
  - 0.6 kg/kW
  - Swiss Hydrogen

Using both H₂ and O₂ from electrolysis yields fuel cell efficiencies of 70%.
Alternative Car Power Trains

2002
HY-POWER
Development with VW

2004
HY-LIGHT
Development with Michelin

2011
Development with Belenos

2015
MIRAI
Toyota

Swiss Competence Center for Biomass Conversion

biosweet
Biomass for Swiss Energy Future
Swiss Competence Center for Energy Research

www.sccer-biosweet.ch

Prof. Dr. Oliver Kröcher
oliver.krocher@psi.ch
The SunCHem Process: Green Gas “Hors Sol”

Nutrients, CO₂, H₂O

CO₂ → H₂O → Photo-Bioreactor → Hydrothermal Gasification → CH₄

Wet Biomass (micro algae)

Power-to-Gas: Methanation Connects Electricity Grid and Natural Gas Grid

- Wind electricity
- Photovoltaics
- Electricity grid
- Electrolysis → H₂
- Natural gas grid
- Gas storage
- Methanation
- CH₄
- CO₂, CH₄ from biogas plants (fermentation)
- CO₂ rich flue gases (from power plants, industry, combustion, blast furnaces, cement industry)
- Gasification
- Gas cleaning
Fluidized Bed Catalytic Methanation
Pilot Plant «GanyMeth»

• Dimensions relevant for scale-up (TRL 6/7): reactor-Ø 21 cm, catalyst bed height up to 2 m, total height 6.50 m
• Pressure range: 1 – 12 bara
• Input variation of gas composition, concentration of water and tars, thereby simulating different combinations of gasifier and gas cleaning
• Start with synthetic gas mixtures
• 21 horizontal and vertical measurement flanges
• Platform for dynamic experiments in the framework of power-to-gas projects: ESI platform (cf. below), RENERG²

Combustion Research Laboratory
Peter Jansohn

Energy conversion processes with high efficiency and low pollutant emissions

gasification conditioning

spray evaporation soot diagnostics
turbulent pre-mixed flames
instationary combustion
catalytic combustion
Laboratory for Catalysis and Sustainable Chemistry: Understanding Catalysis at Relevant Time Scales

- **Fundamental**
  - Bond breaking/formation
  - Reaction kinetics
  - Stability, deactivation

- **Applied**
  - 'learning to do kinetics with spectroscopy'

SwissFEL 2017 and beyond

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Laboratory of Atmospheric Chemistry

- Aerosols and Climate
- CO₂ and Ecosystems
- Aerosols, NOₓ, VOC, Ozone
Production of **Chemical Energy Carriers** for long-term / **seasonal** energy storage

- **Industrial partners**

![Energy System Integration Platform @ PSI](image_url)
Energy System Integration: Connecting Energy Carriers

ESI provides load (negative control power) and stores energy

biomass

ESI provides positive control power and delivers energy

gas grid

electrolysis

O2 storage

H2 storage

CO2 storage

transportation mobility

electricity grid

gas grid

Use of Biomass to Produce Transportation Fuels
Energy Storage and Delivery

Providing Load, Chemical Energy Storage
Use of Biomass to Produce Electricity, Heat, Fuels

Polygeneration

move: Future Mobility Demonstrator @ Empa

Using the Produced Energy Carriers for Transport

PtG for gas vehicles

CNG + H2 driving tests

H2 storage

H2 compressor

350 bar H2 fuelling station

CNG + H2 fuelling station

Erdgas/Biogas (CNG)-Verdichter/Speicher
electrolysis plant

PtG for gas vehicles

CNG + H2 driving tests

350 bar H2-street sweeper

700 bar H2 passenger car

ultrafast / induction BEV charging

700 bar H2 passenger car

ultrafast / induction BEV charging
Mission of «Switzerland Innovation»:
Combination of cutting-edge research and industry at one place in order to bring innovations rapidly to market.

• A federal initiative which aims to provide a value proposition for global companies.

• An instrument of economic promotion, which will provide a contribution towards the effective collaboration between research and industry.

• An opportunity to secure Switzerland’s power of innovation.

• A national network of currently 5 sites of which each site has a clear focus and is complementary to the other sites.

• Competitive to other innovation hubs worldwide.

PARK INNOVAARE:
Part of «Switzerland Innovation»

www.parkinnovaare.ch

PARK INNOVAARE: Planning & Realization
Summarizing Remarks

• Integration of intermittent renewable energies into the system requires options of flexibility / storage, and of adapting the electricity demand to the supply.

• Chemical and electrochemical energy storage must provide a major contribution.

• Catalysis is a key competence to facilitate the inter-conversion between chemical energy carriers, electricity and heat.

• The two SCCERs (Biomass and Storage) integrate the competences of the participating laboratories.

• The full range of 'Technological Readiness Levels' (TRLs) from fundamental investigations (TRL 1-2) to pre-industrial demonstrators (TRL 6-7) must be explored.

• The Energy System Integration Platform enables this step and acts as the proving ground for achieving targets and milestones of the SCCERs.

Acknowledgments

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Thank you for your attention