Developing *transformative* energy technologies: Role of thermal sciences?

D. Poulikakos

Head, Institute of Energy Technology and Director, Laboratory of Thermodynamics in Emerging Technologies

ETH Zurich, Switzerland

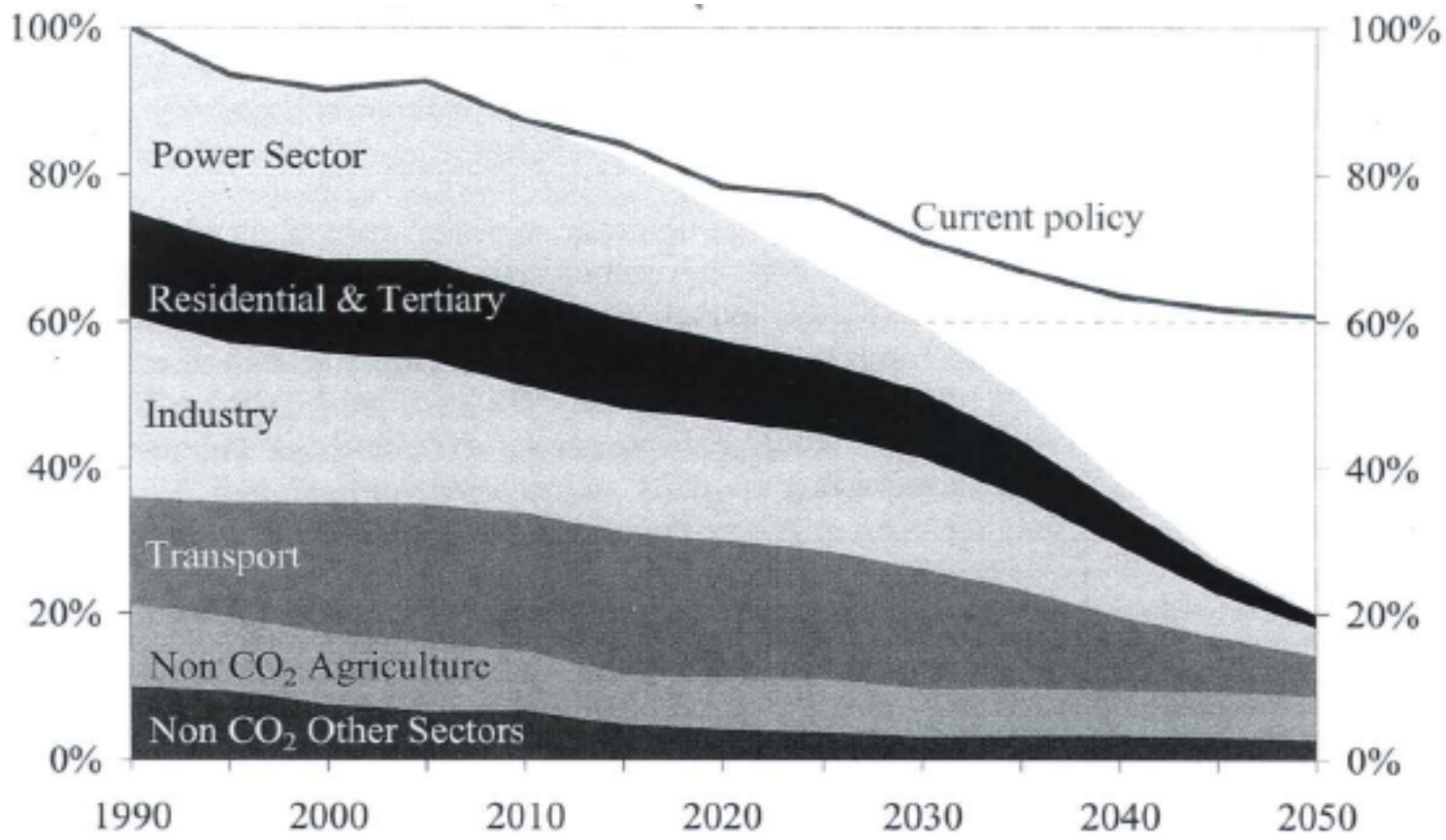
www.ltnt.ethz.ch

dpoulikakos@ethz.ch

General:

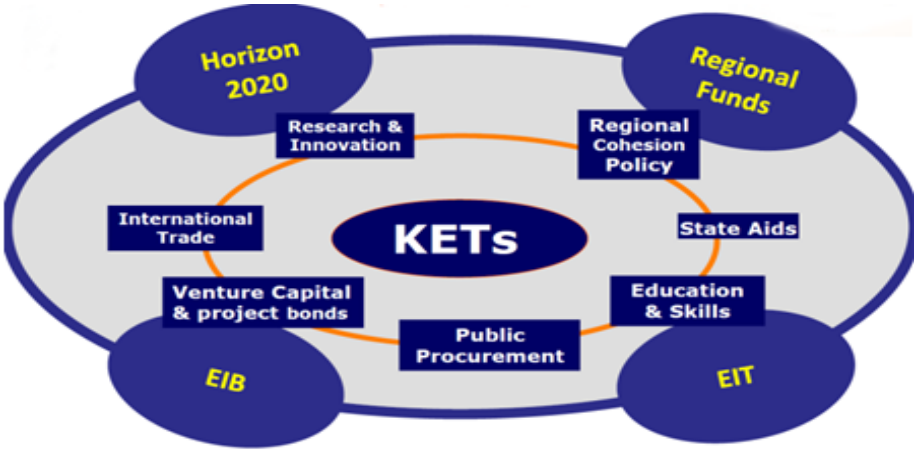
- I call “transformative” energy technologies (conversion, storage, conservation, distribution, or combinations thereof) that can change the state of the art in a disruptive way.
- Great excitement factor from the scientific standpoint - contain the “new and unexplored”
- Difficult to break through
- Require holistic planning from the very beginning

A window of opportunity for transformative technologies



EU GHG emissions toward an 80 % domestic reduction (100% = 1990). Source: EC COM (2011).

EU: Societal needs as research driver



Source: Dirk Beernaert, Reinforcing the competitiveness of Europe Key Enabling Technologies, Micro-nano-electronics and ICT, ESSDERC Workshop on Zero-Power Technologies, 2013.

Some possible areas of exploitation and a possible role of Heat Transfer

- Efficient and affordable storage of intermittent Renewable Energy Source (RES) electricity. *Heat Transfer relevance: Medium to Low*

- Design and production of functional chemical energy carriers (Hydrogen etc.) synthesized from RES through solar-chemical, electrochemical, thermo-chemical and photo-catalytic processes. *Heat transfer relevance: High*

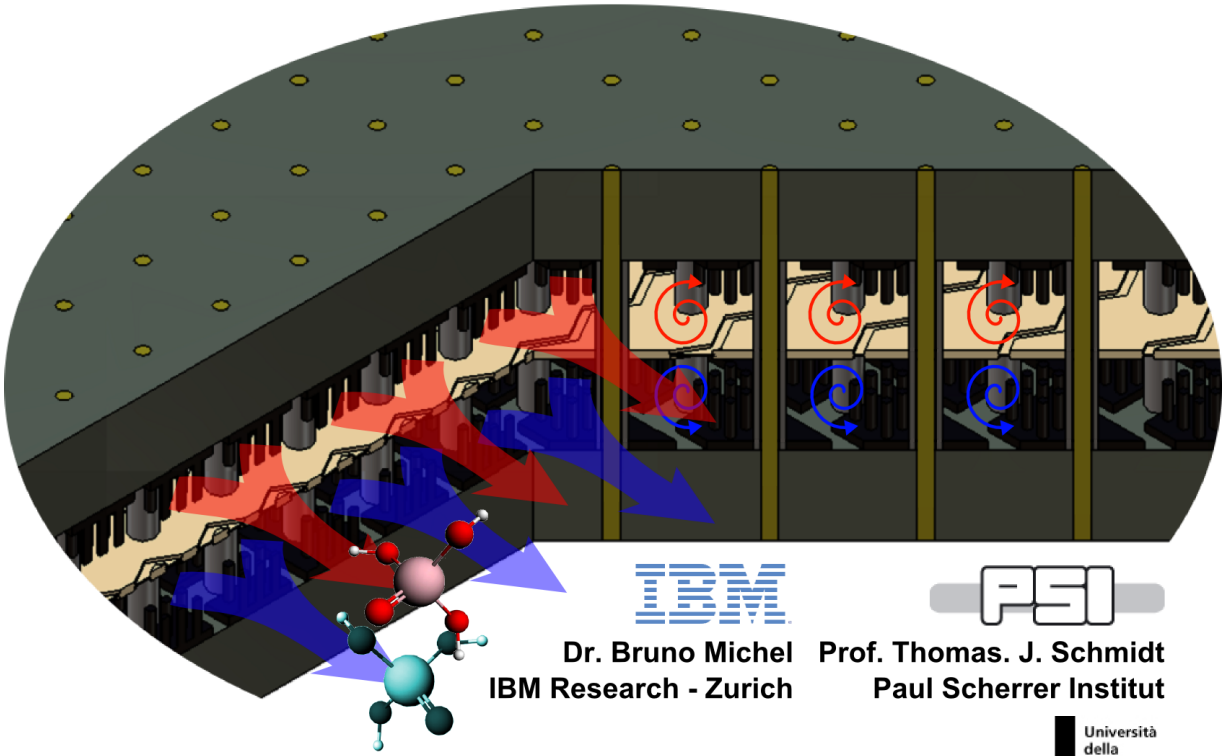
- Solid state devices for direct conversion of sunlight or heat to electricity: *Heat transfer relevance: Medium to high*

- Smart operation of individual systems (homes, cars, trucks, factories, services, power-plants) and their integration. *Heat Transfer relevance: Low*

An example of a Transformative Energy Technology

REPCOOL

Redox flow electrochemistry
for power delivery and cooling



IBM
Dr. Bruno Michel
IBM Research - Zurich

PSI
Prof. Thomas. J. Schmidt
Paul Scherrer Institut

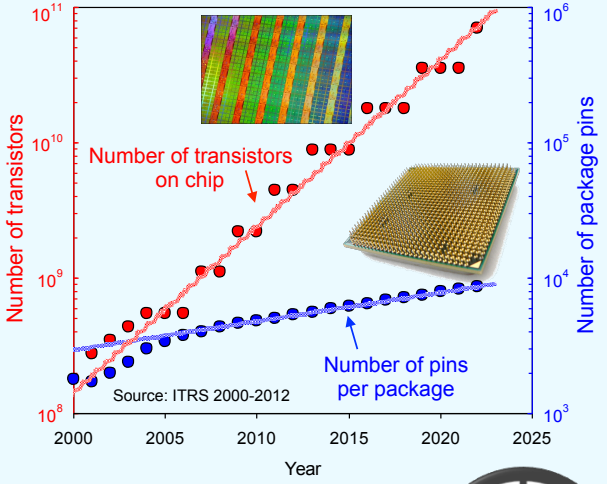
ETH
Prof. Dimos Poulikakos
ETH Zurich

Università della Svizzera italiana
Prof. Michele Parrinello
USI Lugano

A Transformative Concept

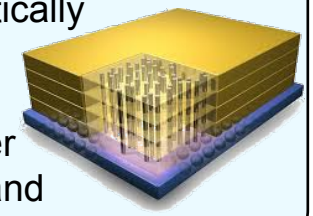
Power vs. signal bandwidth

- Growth in on-chip power demand reduces pins available for communication



- High bandwidth and low latency memory access needed for Big Data and Cognitive Computing

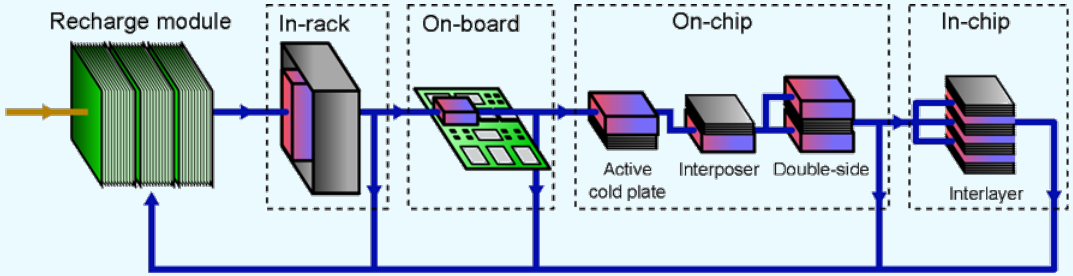
- Trend toward vertically integrated chip packages with even higher power and cooling demand per unit area



Bionic packaging

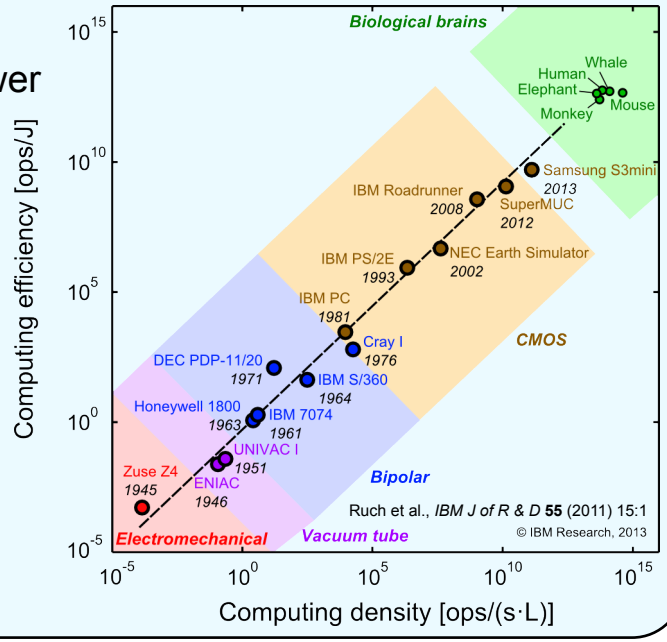
Electrochemical fluids for power delivery & cooling

- Combined cooling and power delivery with redox fluids gives more bandwidth by eliminating power pins



- Liquid cooling and power delivery defines a new "volumetric" scaling paradigm

- Bionic packaging supports evolution toward computing efficiencies and densities approaching biological brains

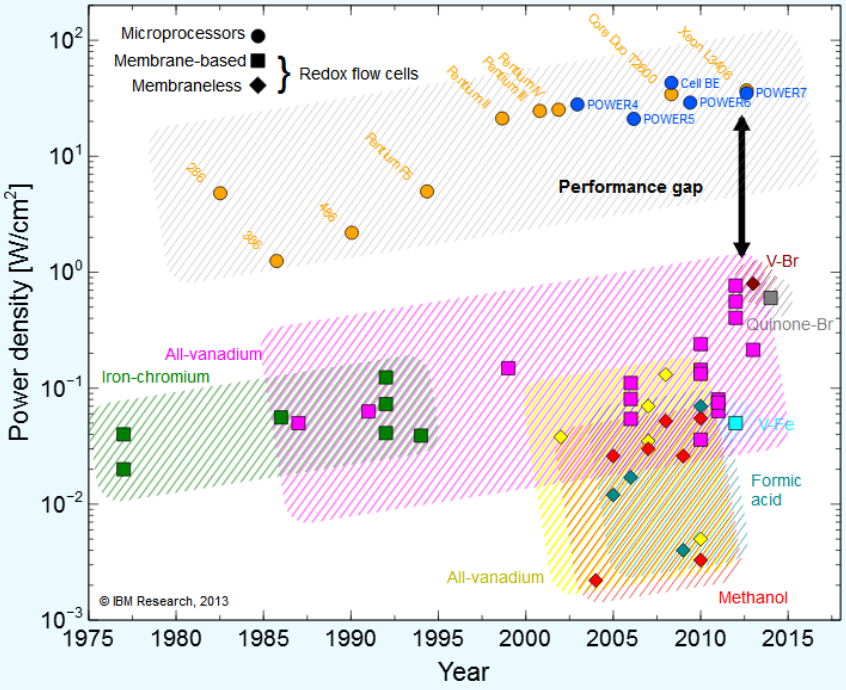


REPCOOL | SNSF Sinergia Grant No. 147 661

The Challenge

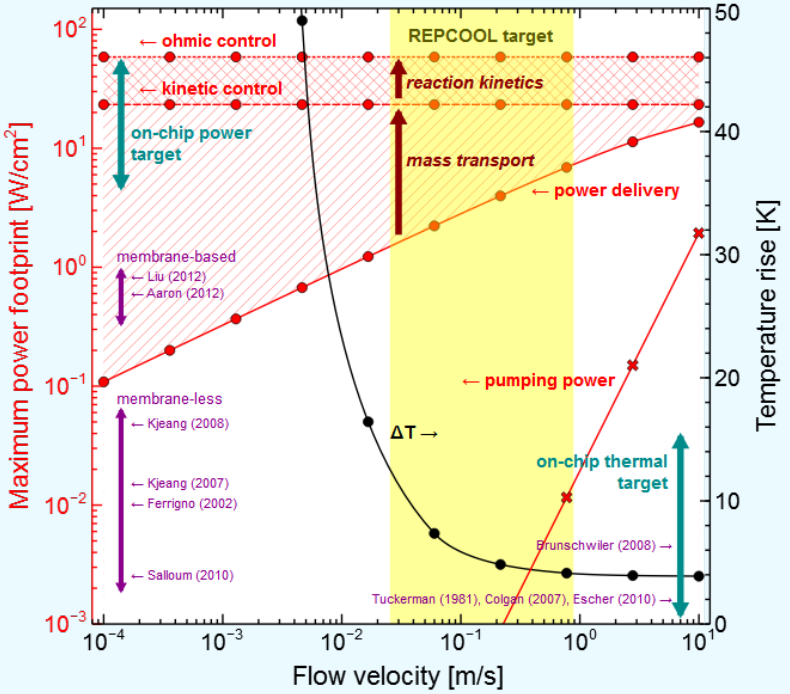
Microprocessor–flow cell power gap

- Existing flow cell architectures can not provide sufficient power density for microprocessors
- There is a need to address power density limitations and develop high-power flow cell designs



REPCOOL strategy

- Synergistic research efforts on integrated cell design, electrochemical system development, and mass transport enhancement
- Simultaneous realization of power density and cooling capacity for microprocessor integration



REPCOOL | SNSF Sinergia Grant No. 147 661

The Transdisciplinarity

Four synergistic efforts:

Applied science

Basic research

1 Device Integration

Dr. Bruno Michel
IBM Research - Zurich

2 Advanced Materials

Prof. Thomas J. Schmidt
Paul Scherrer Institut

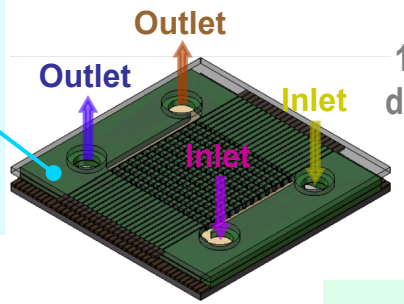
3 Transport Phenomena

Prof. Dimos Poulikakos
ETH Zurich

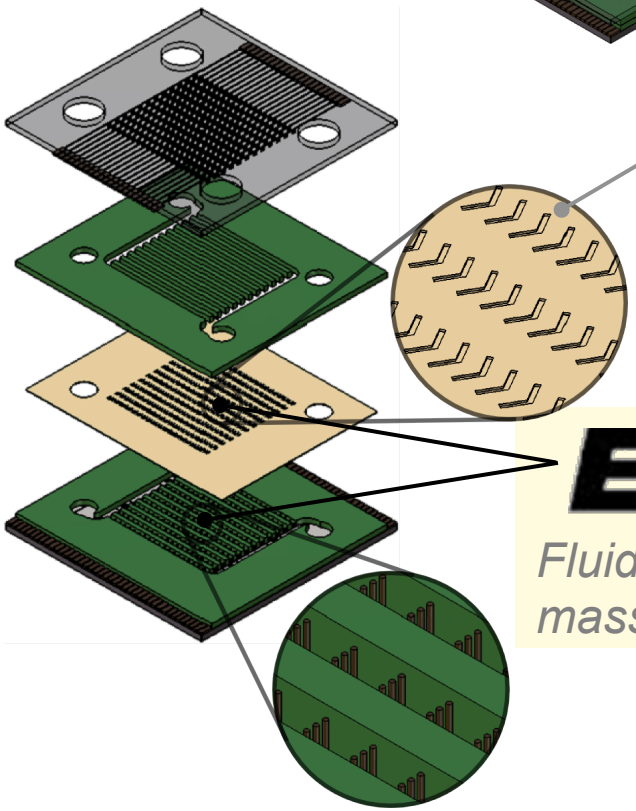
4 Computational Electrochemistry

Prof. Michele Parrinello
USI Lugano

Cell architecture and packaging

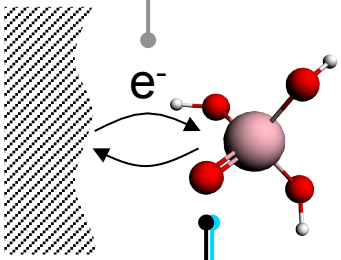


1x1 cm^2 active area device demonstrator



Electrochemical system & membrane

Fluid flow and mass transfer



Electrochemical system modeling

REPCOOL | SNSF Sinergia Grant No. 147 661