Food-Energy-Water Nexus:
Convergence Framing for Research and Innovation

FUTURE OF FOOD AND
THE ROLE OF TECHNOLOGY
CoNFoMa2018
September 8, 2018
Minneapolis, MN

Pramod P. Khargonekar
University of California, Irvine

UCI University of California, Irvine

Outline

Context

Food-Energy-Water Nexus – NSF INFEWS Initiative

Convergence Model for Research

Research to Innovation

Conclusions

Overall Context

Climate change and global warming

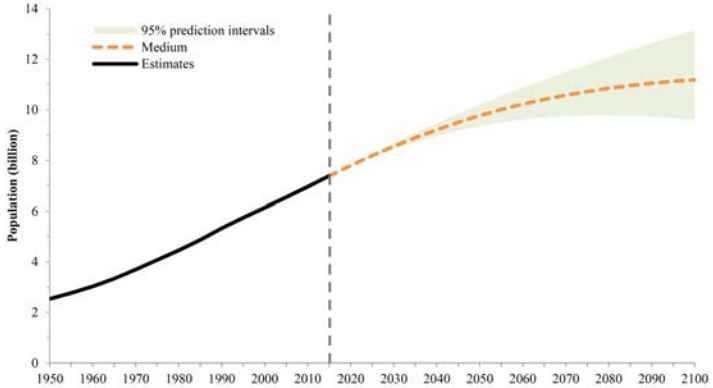
Interactions and feedback between natural systems and man-made systems

Socio-economic-technological, heterogenous, distributed, man-made system

Multiple players and institutions interacting with each other

Global demographic shifts will drive the coming decades

Figure 2. Population of the world: estimates, 1950-2015, and medium-variant projection with 95 per cent prediction intervals, 2015-2100



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

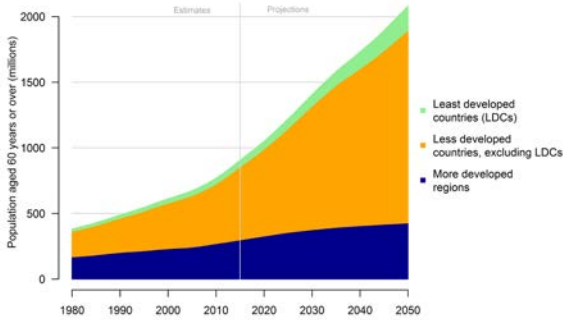
TABLE 1. POPULATION OF THE WORLD AND REGIONS, 2017, 2030, 2050 AND 2100, ACCORDING TO THE MEDIUM-VARIANT PROJECTION

Region	*Population (millions)*			
	2017	*2030*	*2050*	*2100*
World	7 550	8 551	9 772	11 184
Africa	1 256	1 704	2 528	4 468
Asia	4 504	4 947	5 257	4 780
Europe	742	739	716	653
Latin America and the Caribbean	646	718	780	712
Northern America	361	395	435	499
Oceania	41	48	57	72

Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

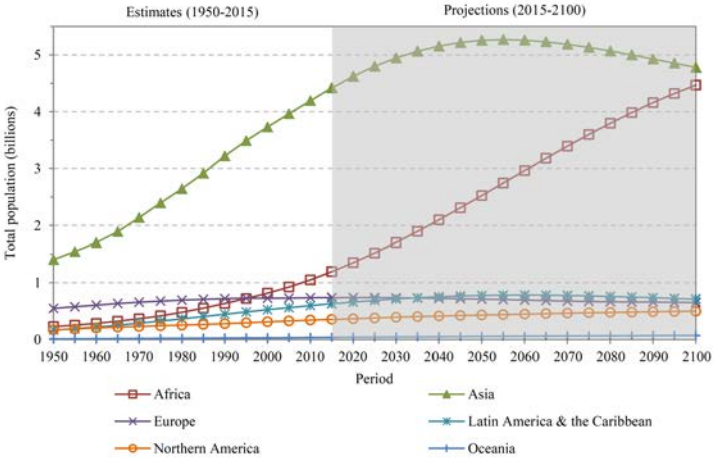
Figure 1.

Number of persons aged 60 years or over by development group,[1] from 1980 to 2050



Data source: United Nations (2017). World Population Prospects: the 2017 Revision.

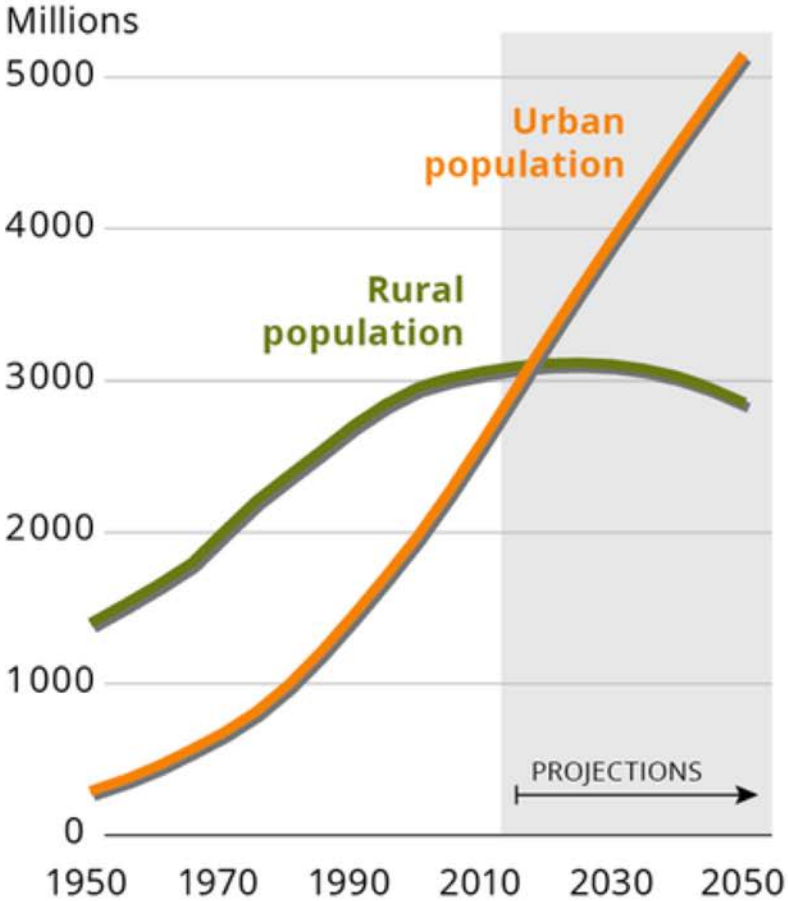
Figure 3. Population by region: estimates, 1950-2015, and medium-variant projection, 2015-2100



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

Less developed regions

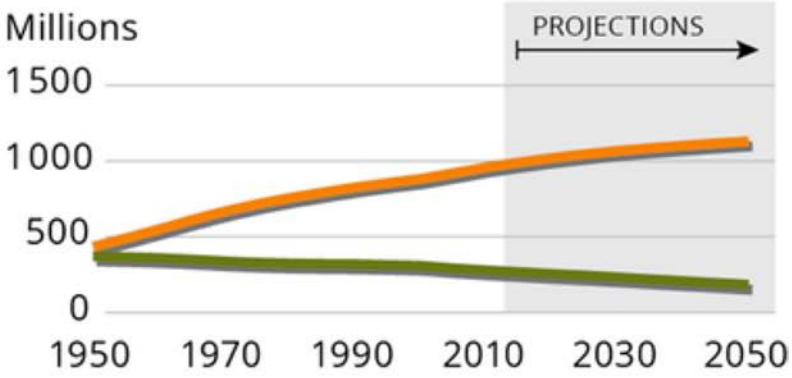
Africa, Asia (excluding Japan), Latin America and the Caribbean, Melanesia, Micronesia and Polynesia.



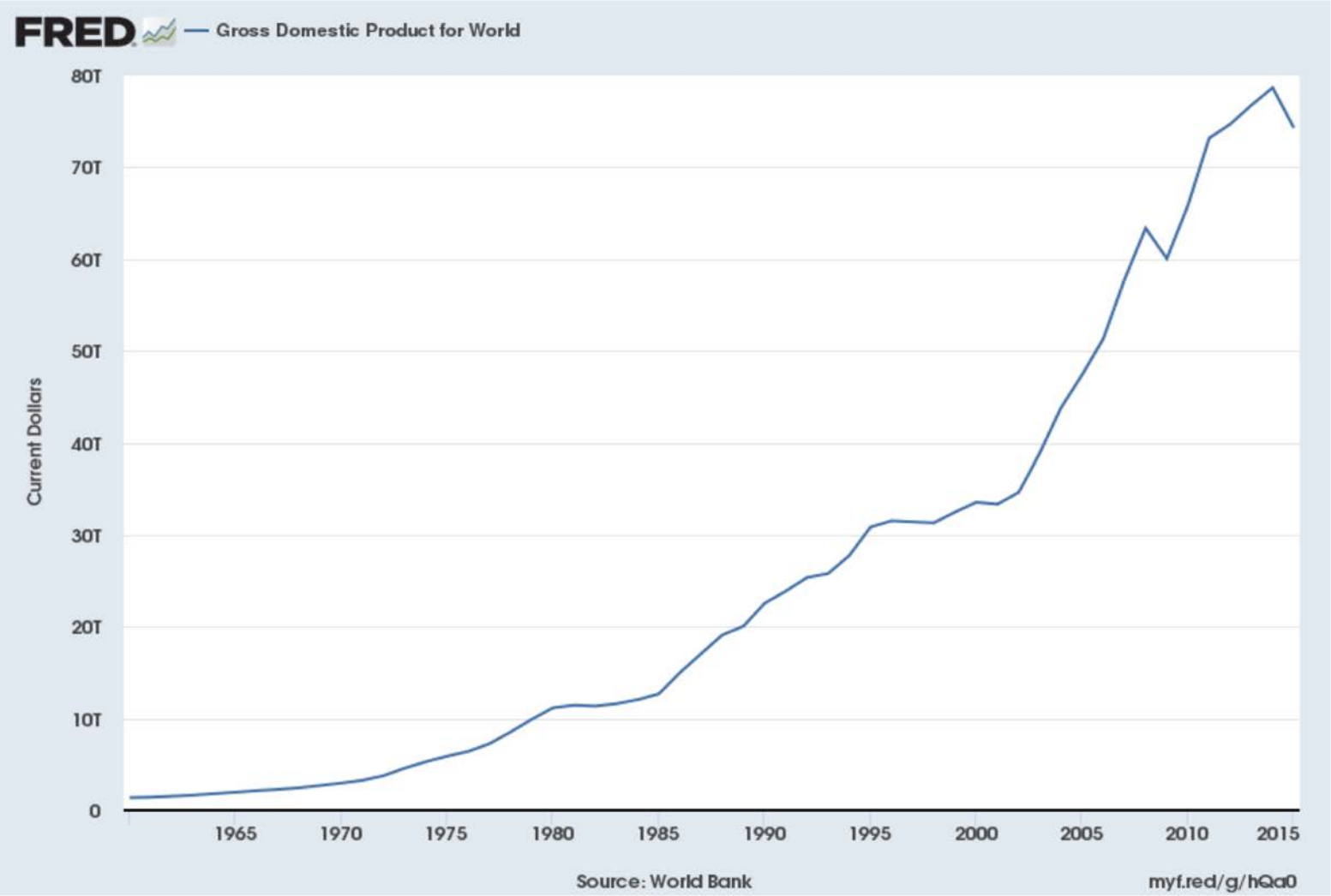
Urbanization is the dominant trend

More developed regions

Europe, Northern America, Australia, New Zealand and Japan.

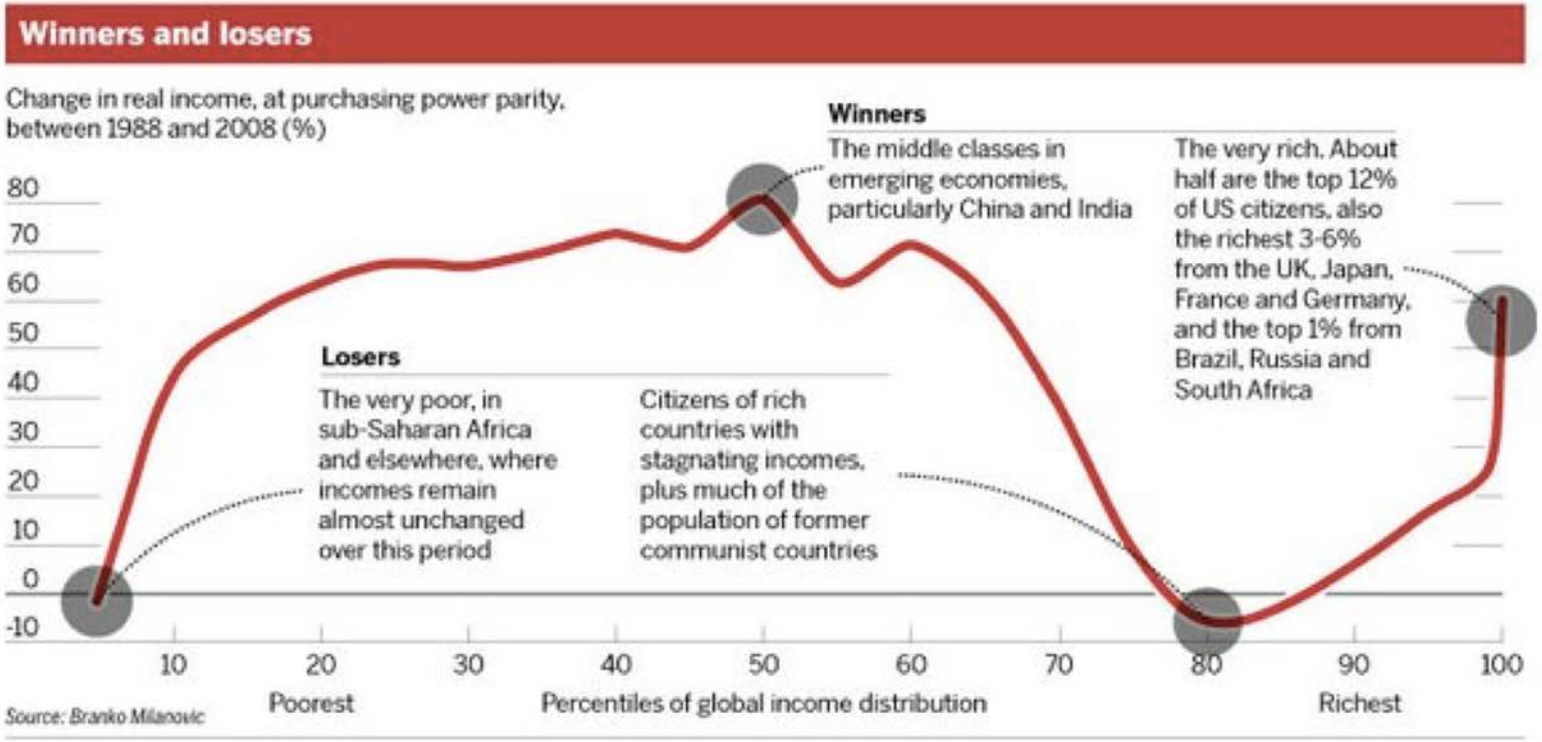


Source: European Environment Agency, UN



Dramatic economic growth

Dramatic increase in global middle class
but great increase in inequality within nations



Additional Drivers

Trade – local, national, regional, global

Markets, prices, business competition

Changes in diets

Governance

Cultures

Resource Implications

60% more food will be needed by 2050

80% more energy consumption by 2050

50% more water withdrawals in the developing nations by 2025

18% more water water withdrawals in the developed nations by 2025

Water for Energy

NSF/EPRI Collaboration on "Water for Energy"- Advanced Dry Cooling for Power Plants

PROGRAM SOLICITATION
NSF 13-564

National Science Foundation

Directorate for Engineering
Division of Chemical, Bioengineering, Environmental, and Transport Systems

Electric Power Research Institute

"The "water-for-energy" issue is an important piece of the Energy-Water nexus. The goal of this collaboration is to leverage the complementary missions of … (EPRI) and … (NSF) to foster … research and technology development that will lead to significant reductions or elimination of the use of water for cooling power plants."

ARPA-E ARID Program

ARID

Advanced Research In Dry cooling

arpa·e

CHANGING WHAT'S POSSIBLE

"ARPA-E's Advanced Research In Dry cooling (ARID) program comprises projects that are aimed at maintaining the efficiency of U.S. electric power generation, which otherwise could suffer due to regional water shortages."

Food-Energy-Water in FY15 at NSF

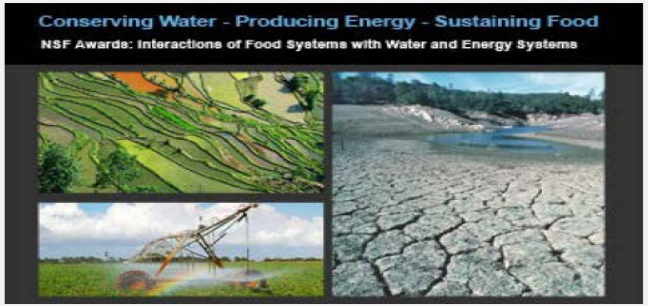
17 workshop grants

- Designed to facilitate partnerships among researchers
- Integrate scientific communities, including those at other federal agencies; enhance communication
- Define fundamental science and engineering research needs/questions in FEW Systems

Press Release 15-090

New grants foster research on food, energy and water: a linked system

Amid population growth, drought and increased urbanization, understanding food, energy and water availability is increasingly important



How food, water and energy systems interact: a photo gallery.
Credit and Larger Version

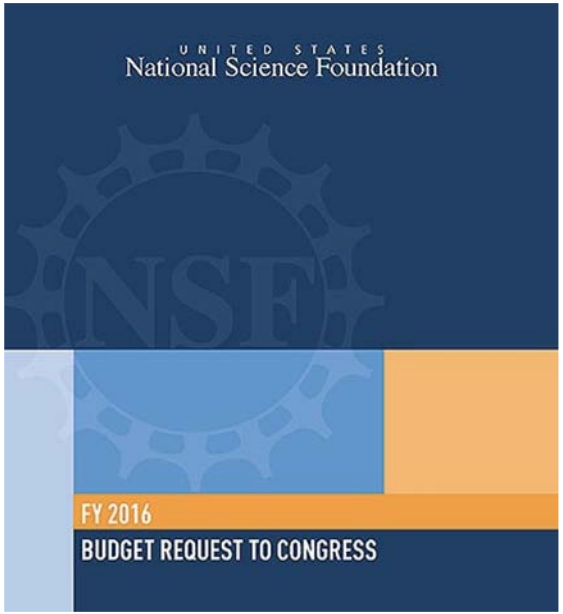
August 14, 2015

In a world where a growing number of people lack food, water and sources of energy, providing these resources has become a challenge.

To find new answers, the National Science Foundation (NSF) has funded 17 grants, totaling $1.2 million, to support workshops on the interactions of food, energy and water, or FEW. Additionally,

NSF FY 2016 Budget Request

"Innovations at the Nexus of Food, Energy and Water Systems (INFEWS), $75 million, is an NSF-wide investment that aims to understand, design, and model the interconnected food, energy, and water system through an interdisciplinary research effort that incorporates all areas of science and engineering and addresses the natural, social, and human-built factors involved."



https://www.nsf.gov/news/news_summ.jsp?cntn_id=134032

NSF INFEWS Initiative – Four Pillars

Advance understanding of the FEW system through quantitative and computational modeling

Develop real-time, cyber-enabled interfaces that improve understanding of the behavior of FEW systems and increase decision support capability

Enable research that will lead to innovative solutions to critical FEW problems

Grow the scientific workforce capable of studying and managing the FEW systems

A Systems Theorist view of Food-Energy-Water Nexus


Bonn2011 Conference
The Water, Energy and
Food Security Nexus
Solutions for the Green Economy
16 – 18 November 2011
Understanding the Nexus
Background paper for the Bonn2011 Nexus Conference
BONN PERSPECTIVES
A FRESH LOOK AT SUSTAINABILITY

H. Hoff, 2011

Opportunities using the Nexus Framing

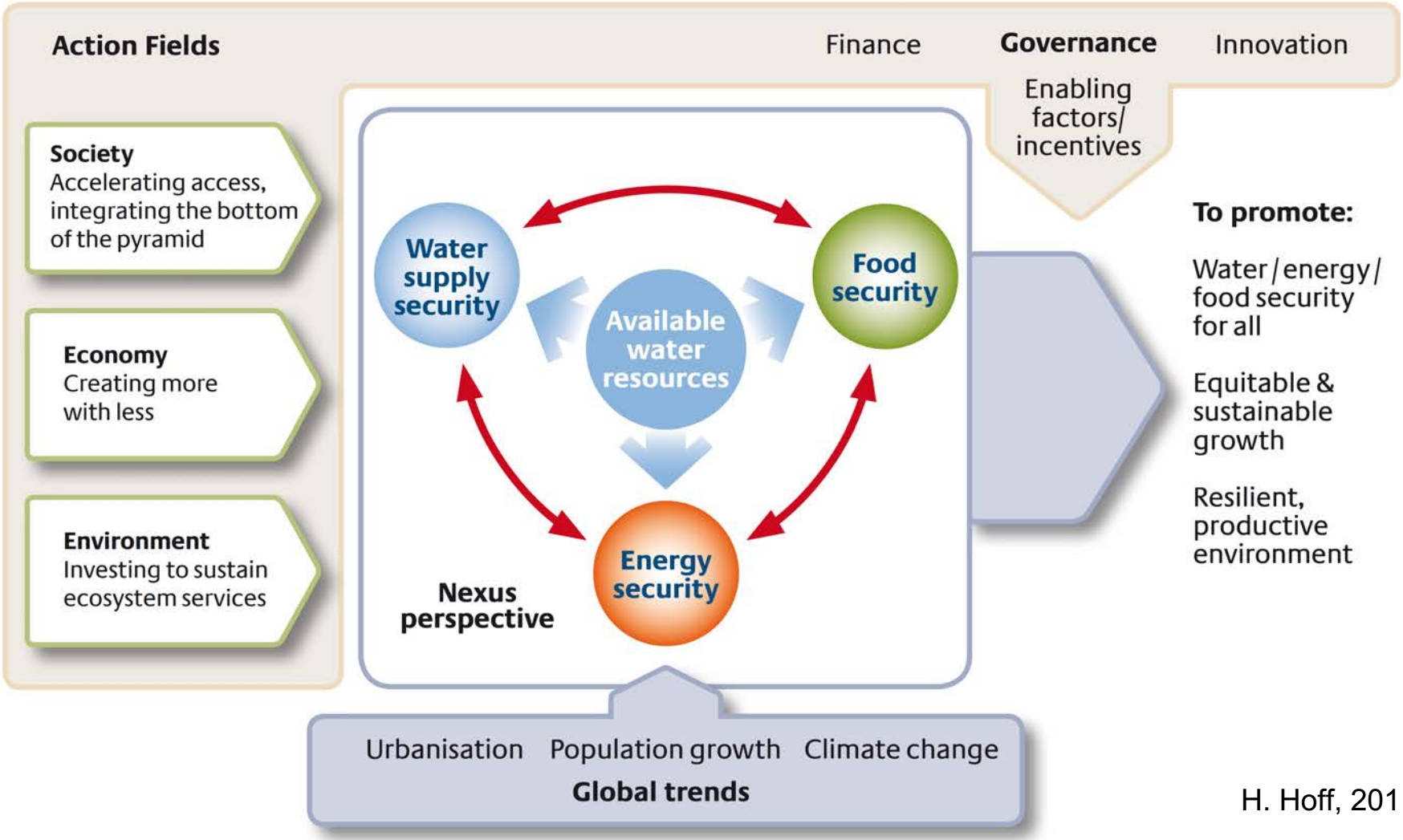
Increased productivity from resources through technological innovation

Waste as a resource in multi-use systems

Economic incentives and avoidance of sunk costs through nexus thinking

Governance, institutions, policy coherence

H. Hoff, 2011


Action Fields
Finance
Governance
Innovation
Enabling factors/ incentives
Society
Accelerating access, integrating the bottom of the pyramid
Economy
Creating more with less
Environment
Investing to sustain ecosystem services
Water supply security
Food security
Available water resources
Energy security
Nexus perspective
To promote:
Water / energy / food security for all
Equitable & sustainable growth
Resilient, productive environment
Urbanisation
Population growth
Climate change
Global trends

H. Hoff, 2011

Water for Energy

Power plant cooling

Fossil fuel extraction and processing, e.g, fracking, oil sands

Water for biofuel production

Hydropower

Table 1. Water productivity in electricity production.

	Photo-voltaics	Concen-trating solar power	Gas	Coal / oil / nuclear	Hydro-power	Biofuels
m^3 / MWh	~ 0	~ 2	~ 1	~ 2	~ 60 (variable)	~ 180 (variable)

Note that the extraction and processing of fossil fuels adds between 0.05–1 m3 / MWh to these figures.)

H. Hoff, 2011

Energy for Water

Pumping of water

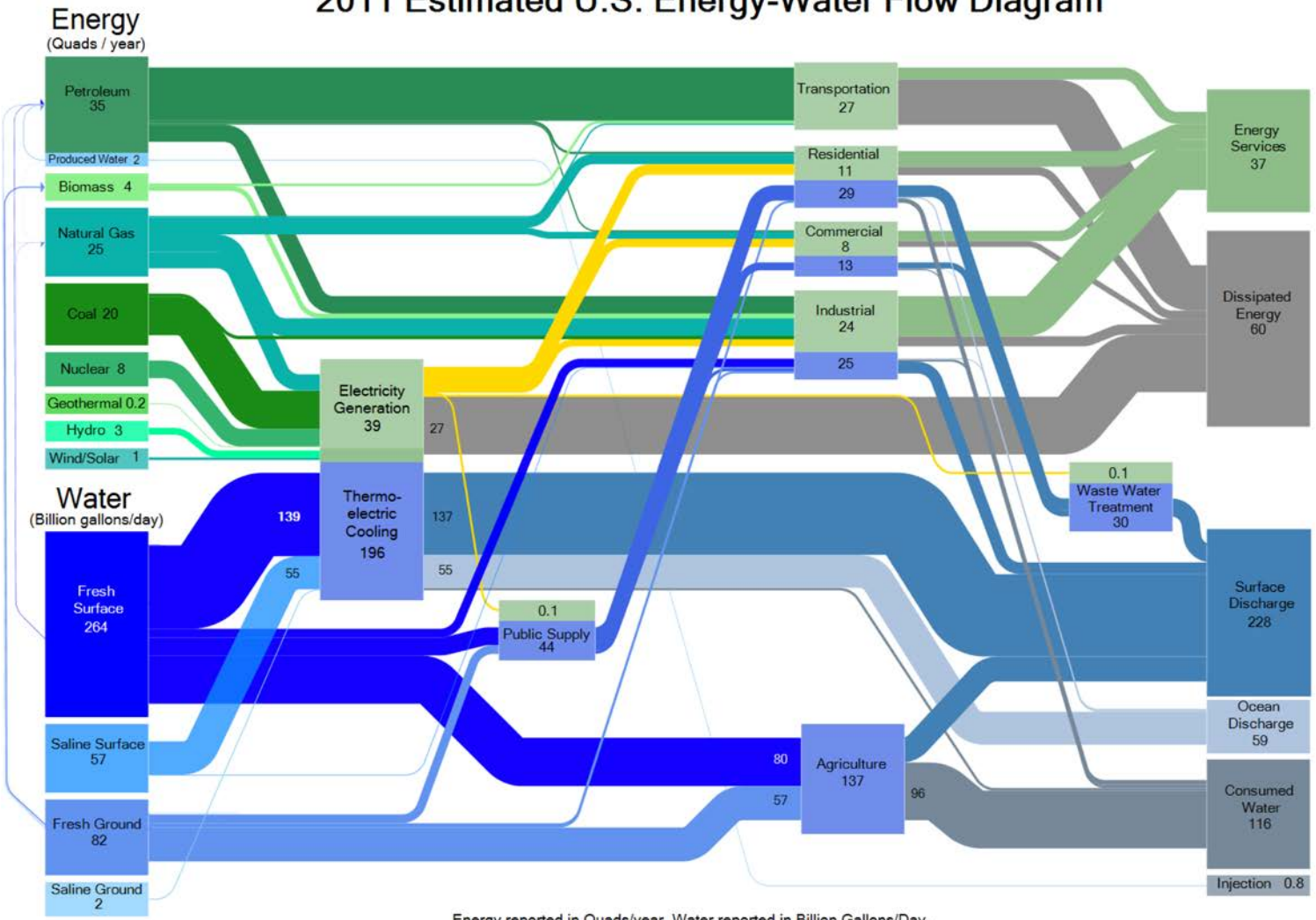
Transportation of water

Distribution of water

Treatment of water

Desalination

2011 Estimated U.S. Energy-Water Flow Diagram



Energy reported in Quads/year. Water reported in Billion Gallons/Day.

https://www.energy.gov/sites/prod/files/2014/06/f16/Water%20Energy%20Nexus%20Report%20June%202014.pdf

Food and Water System Interactions

Precipitation patterns leading to increasing variability in water and soil moisture

Rising demand for water for agricultural production

Water demand from different agricultural sectors:

- Crops
- Fisheries
- Live stock
- Aquaculture

Crop Production and Processing

Key imperative: increase water use efficiency in crop production

Optimal use of rain water and ground water

Possible approach through data, sensing and control

Negative impact of agriculture water run-off on water quality

Livestock Production and Processing

Water and land impacts of livestock production and processing

Drinking, feed production, servicing of animals

Manure, nutrients, pathogens, drug residues impact on water quality and land degradation

Possible approach: treatment of polluted water at point-source

Water for Food

Table 2. Ranges of water productivity of different crops in kcal per m³ and USD per m³ of water[146]

	Wheat	Potato	Tomato	Apple
kcal per m³	660–4000	3000–7000	1000–4000	520–2600
USD per m³	0.04–1.2	0.3–0.7	0.75–3.0	0.8–4.0

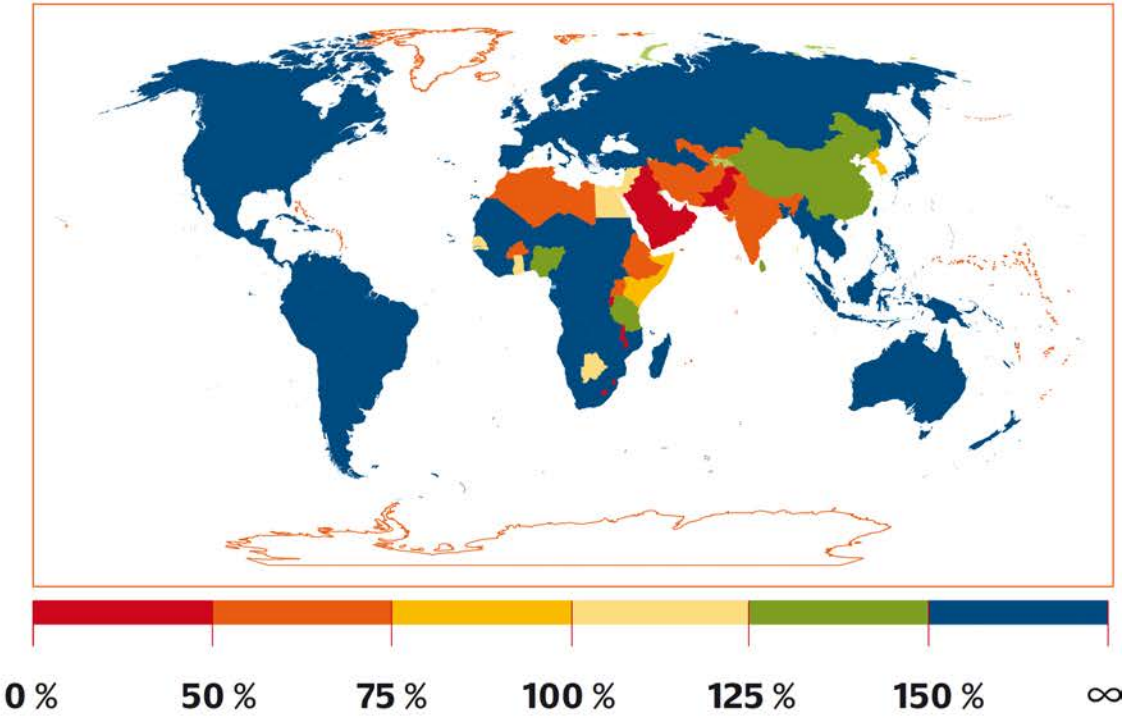
Table 3. Global average water productivity (in kcal per m³), and consumptive water-use from grazing (in per cent), of selected livestock products[148]

	Meat from beef cattle	Meat from sheep and goats	Milk from dairy cattle	Meat from pigs	Meat from poultry	Eggs from poultry
Global average water productivity in kcal / m³	34	30	332	666	371	578
Water-use from grazing in %	84	75	80	0	0	0

H. Hoff, 2011

Figure 4. The water-food (and land) link: water-constrained potential for food self-sufficiency in % at country level

Water scarcity defined as the percentage ratio between green-blue water availability and the water requirements for producing a daily diet of 3,000 kcal with 20% animal products



Source: Gerten et al., 2011

WATER

The paradox of irrigation efficiency

Higher efficiency rarely reduces water consumption

By R. Q. Grafton[1,2], J. Williams[1], C. J. Perry[3], F. Molle[4], C. Ringler[5], P. Steduto[6], B. Udall[7], S. A. Wheeler[8], Y. Wang[9], D. Garrick[10], R. G. Allen[11]

748 24 AUGUST 2018 • VOL 361 ISSUE 6404

"Advanced irrigation technologies that increase IE may even increase on-farm water consumption, groundwater extractions …, and water consumption per hectare …"

"A key constraint to better decision-making is inadequate estimates of water inflows and outflows at watershed and basin scales. This analysis of water accounts is essential to demonstrate when IE policies are or are not in the public interest."

Agriculture impact on Water

Fertilizer run-offs and water degradation

Groundwater recharge

Land and soil degradation

Energy for Food

Food supply chain accounts for about 30% of total energy demand

Fertilizer production

Food processing and transportation

Oil prices are highly correlated with food prices

For some foods, energy productivity < 1

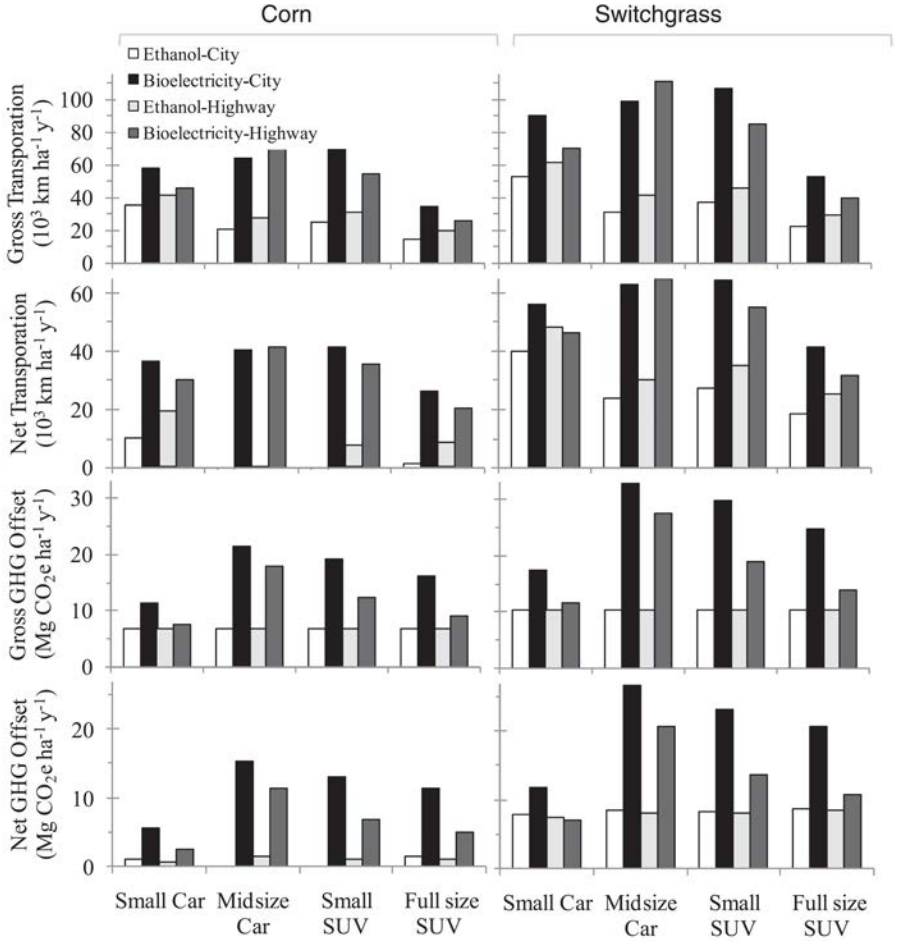


Fig. 2. Transportation and GHG offsets from bioelectricity and ethanol, based on a range of vehicle classes, agriculture systems, and energy conversion technologies. The net output accounts for co-products as well as for input in the fuel cycle and vehicle cycle. Results are not plotted for cases when a further distance could be traveled with input energy than with gross output energy (*24*).

Campbell et al, 2009

Environmental Science & Policy 69 (2017) 113–123

Contents lists available at ScienceDirect

Environmental Science & Policy

journal homepage: www.elsevier.com/locate/envsci

The water-energy-food nexus: Is the increasing attention warranted, from either a research or policy perspective?

Dennis Wichelns*

Stockholm Environment Institute, Asia Centre, Bangkok, Thailand

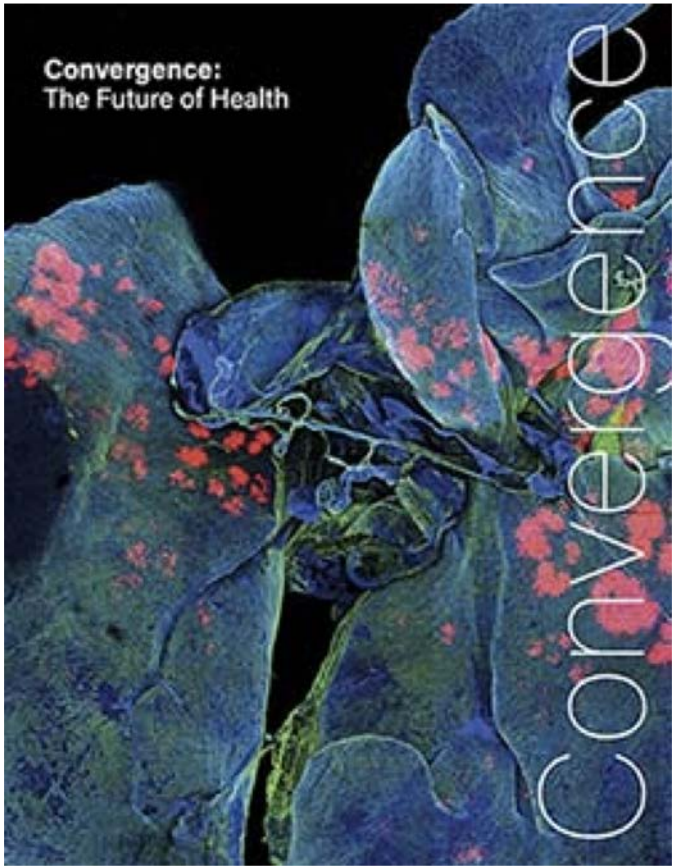
“The increasing interest in the nexus discourse likely has been motivated also by the increasing awareness among scholars and public officials that processes influencing the sustainability of natural resources are dynamic, complex, and uncertain.”

“Yet the increasing interest, alone, might not be sufficient to overcome the challenges that have thwarted earlier efforts to implement integrative policy programs, such as those prescribed by INRM and IWRM.”

Wichelns, 2017

How might Convergence Research Paradigm Advance Food-Energy-Water Nexus Solutions?

MIT 2016



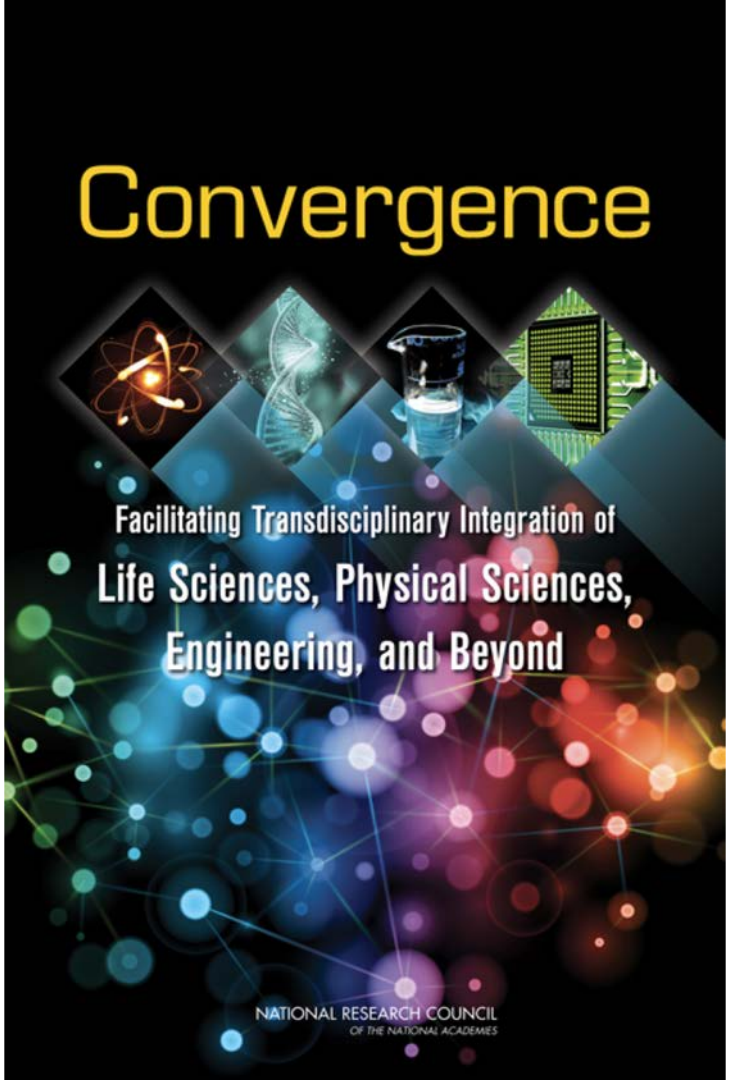
MIT Report - Convergence: Future of Health

"Convergence as applied to health … **integrates** expertise from life sciences with physical, mathematical, and computational sciences, as well as engineering, to form **comprehensive** frameworks … "

"… convergence goes beyond collaboration … involves **integration** of historically distinct disciplines and technologies into a **unified** whole … integration … offers **potentially revolutionary change** for biomedical sciences."

Sharp et al 2016, Science,
Capitalizing on convergence for health care

NRC 2014


Convergence
Facilitating Transdisciplinary Integration of
Life Sciences, Physical Sciences,
Engineering, and Beyond
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

NRC Report on Convergence

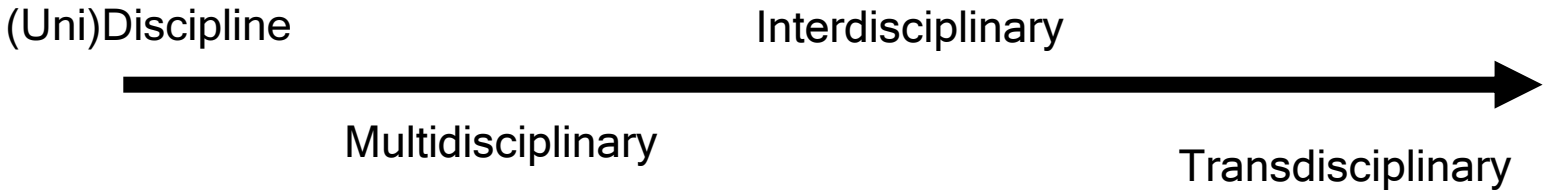
Convergence is an approach to **problem solving** … **integrates** knowledge, tools, and ways of thinking .. a **comprehensive synthetic framework** for tackling scientific and societal challenges ...

Two closely related but distinct properties:

- convergence of expertise
- formation of the web of partnerships.

Source: Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond, NRC, 2014

What is Convergence?



Source: Hall, 2014

Disciplines and Multidisciplinary

Discipline: particular branch of learning or body of knowledge

Multidisciplinarity: juxtaposition of two or more disciplines on a question, problem, topic, or theme.

- **Juxtaposition** of disciplines that remain separate
- Individuals **work separately,** results typically published separately or compiled, but **not synthesized.**

Source: Hall, 2014

Interdisciplinary

Interdisciplinary: integration of information, data, methods, tools, concepts, and/or theories from two or more disciplines

- Key defining concept: **integration**
- Individuals may work alone, but increasingly research is **team-based.**
- Collaboration introduces **social integration**, project management and communication.

Source: Hall, 2014

Transdisciplinary

Transdisciplinary: transcend disciplinary approaches through comprehensive frameworks and paradigms

- **Problem-oriented** research that crosses the boundaries of both academic and public and private spheres.
- **Mutual learning**, joint work, and knowledge integration are key to solving “real-world” problems.
- Beyond interdisciplinary combinations to foster **new worldviews** or domains.

Source: Hall, 2014

NRC Report on Convergence

Convergence is an approach to **problem solving** … **integrates** knowledge, tools, and ways of thinking .. a **comprehensive synthetic framework** for tackling scientific and societal challenges ...

Two closely related but distinct properties:

- convergence of expertise
- formation of the web of partnerships.

Source: Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond, NRC, 2014

Convergence and Pressing Societal Needs

=

Grand Challenges?

UN Sustainable Development Goals

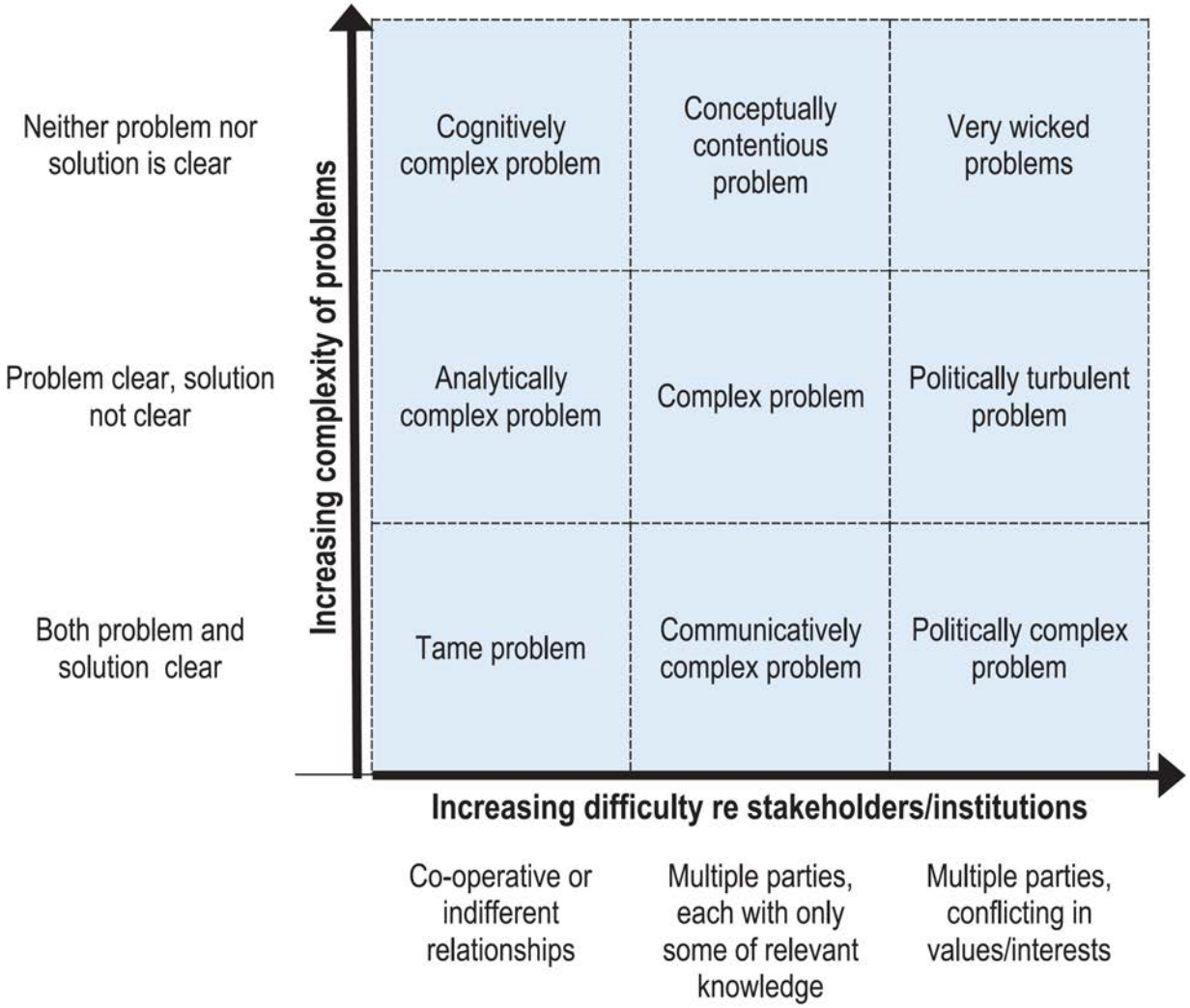
Grand Challenges are often Wicked Problems

Wicked problems … there is no clear stopping rule … working on it more … better solution … no single right answer … every attempt can matter because it affects the things people depend upon.

Horst and Rittel, 1973

Characteristics of Wicked Problems

- No definite formulation of a wicked problem.
- No stopping rules.
- Solutions are not true-or-false, but better or worse.
- No immediate and no ultimate test of a solution to a wicked problem.
- Do not have an enumerable (or an exhaustively describable) set of potential solutions
- Every wicked problem is essentially unique.
- Causes can be explained in numerous ways.



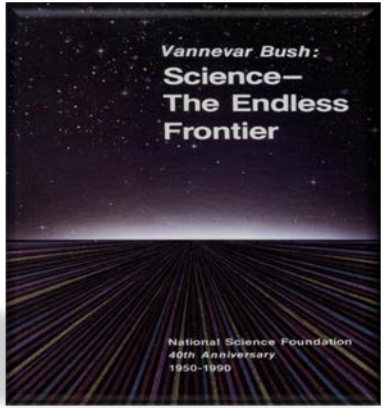
Alford and Head, 2017
Wicked and less wicked problems: a typology and a contingency framework
Policy and Society, 36:3, 397-413

Are Food-Energy-Water Nexus Problems Wicked?

Research will not Suffice – We Need Innovations

Research to Innovation

- New knowledge leads to societally useful innovations
- Tremendous acceleration after the industrial revolution
- Rise of science and engineering research ecosystem after the 2nd WW



Science offers a largely unexplored hinterland for the pioneer who has the tools for his task. The rewards of such exploration both for the Nation and the individual are great. Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress.

It is Getting Harder to Innovate

Figure 1: Aggregate Data on Growth and Research Effort

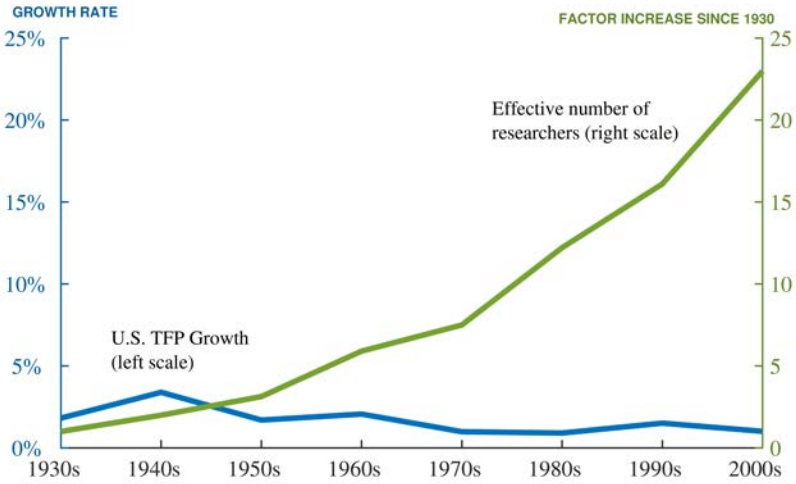
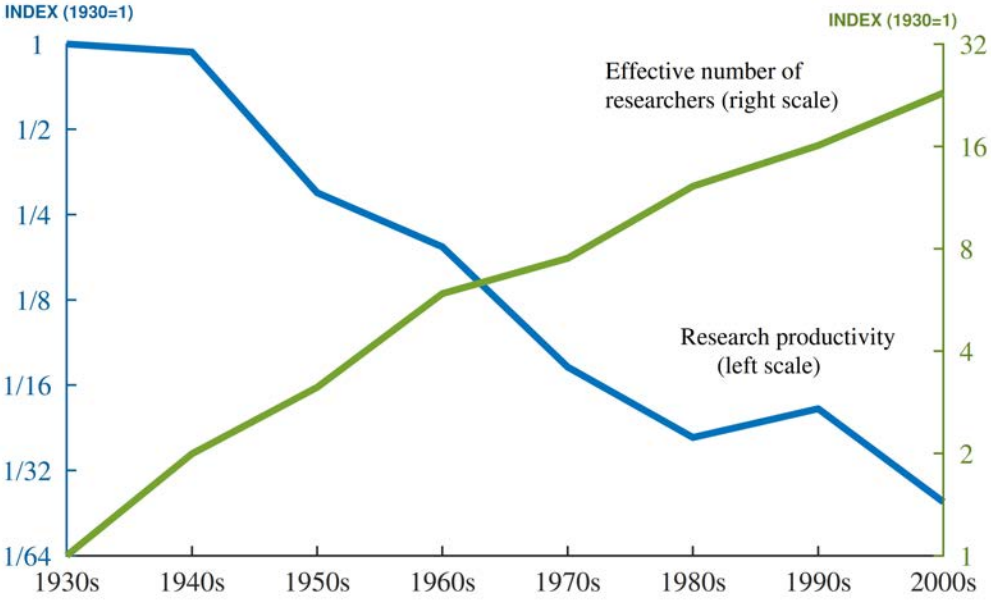


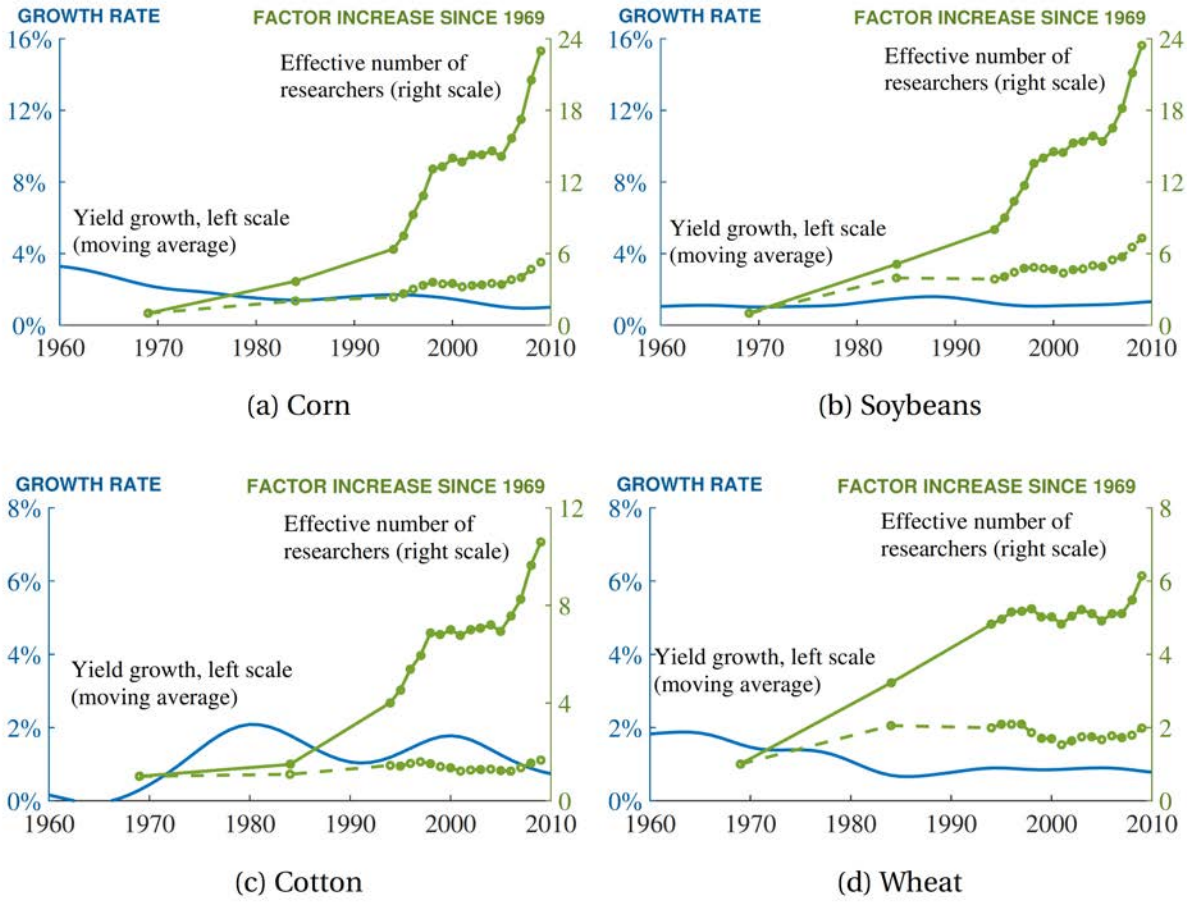
Figure 2: Aggregate Evidence on Research Productivity



Note: Research productivity is the ratio of idea output, measured as TFP growth, to research effort. See notes to Figure 1 and the online data appendix. Both research productivity and research effort are normalized to the value of 1 in the 1930s.

Source: Are Ideas Getting Harder to Come by, Bloom et al, 2017

Case of Agriculture Crops



Source: Are Ideas Getting Harder to Come by, Bloom et al, 2017

Next Green Revolution

https://www.nytimes.com/2016/01/04/opinion/we-need-a-new-green-revolution.html

OP-ED CONTRIBUTORS

We Need a New Green Revolution

By Phillip A. Sharp and Alan Leshner

Jan. 4, 2016

…one that goes beyond advancing production to focus on reducing exorbitant rates of food loss

Zia Khan
Rockafeller Foundation

https://www.nytimes.com/2016/01/14/opinion/what-the-next-green-revolution-will-require.html

Small-scale farmers still feed a majority of the world and must therefore be at the center of any future agricultural research agenda.

R. Offenheiser
President, Oxfam America

Comments

Ideas

Questions?

pramod.Khargonekar@uci.edu
http://faculty.sites.uci.edu/khargonekar/