

# The Future of Chemical Engineering is Bright...

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Jacques Villermaux Award lecture ECCE/ECAB Berlin 2023

# New Vistas for Chemical Engineering

- Villermaux – 1996 - microscale
- Charpentier – 2005 - multiscale
- Ottino – 2011 - complexity
- Ramkrishna – 2022 – sustaining the core

# My career journey

- Process Systems Engineering - Engineering and Mathematics and Computation
- Industry then back to academia
- PSE – Digitalisation/Smart Manufacturing/Industry 4.0
- Biology and Physiology
- Engineering Ethics
  
- Doctoral researchers and early career researchers

# Summary

- Perspectives
  - Smart Process Manufacturing, Sustainability, Biology
- Concerns
  - The future is bright – but...



Switzerland 1900



UK 1950



Japan 2015

# Smart (Process) Manufacturing – responsive to customer supply chains

- Factory enterprise integration and plant-wide optimization – **in practice**
- Manufacturing Intelligence – **in progress**
- Disruptive Business Models - **?**

# Smart Manufacturing technical research challenges

- ‘Who knows?’ - Flexibility and uncertainty
- ‘I want it now!’ - Responsiveness and agility
- ‘Can you guarantee it?’ - Robustness and security
- ‘What do you want?’ - Selling molecules, mixtures or function?
- ‘Please help!’ – Enablers

# The Process Systems Engineering toolkit

- Integrated decision making of complex systems
- Simulation, Optimization, Control, Supply chain modelling, multiscale modelling, AI
- Understanding, Analysis, Design, Operations
- Systems thinking



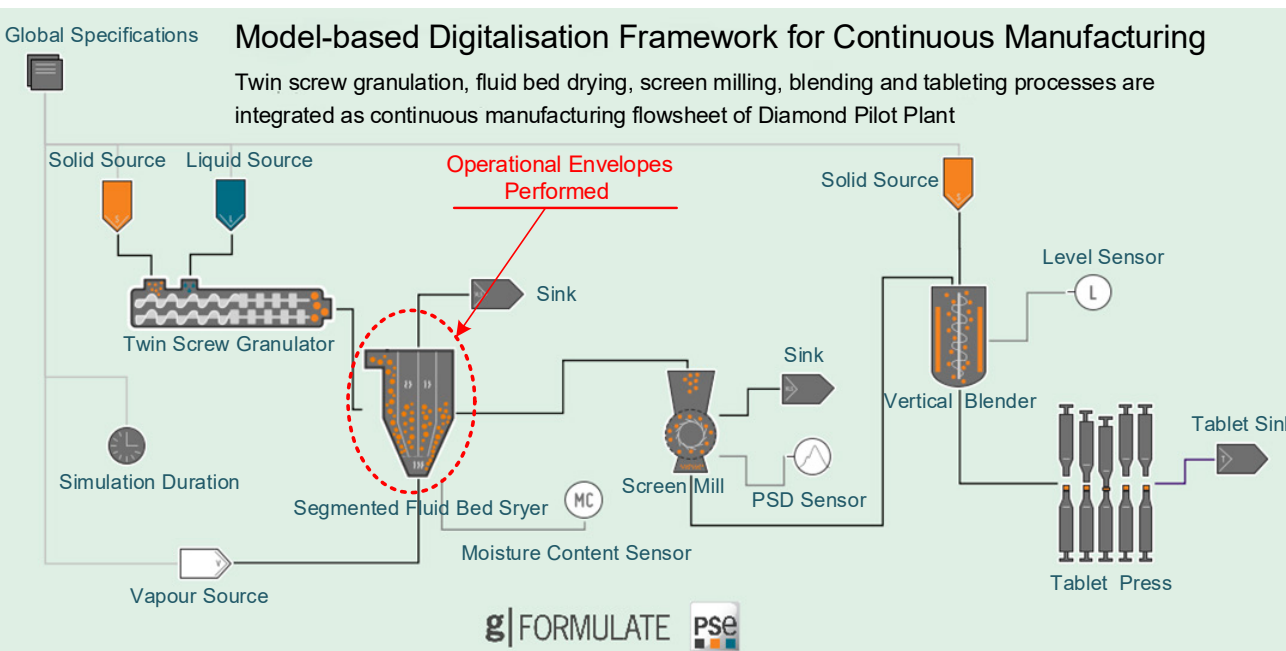
## Current PSE Curricula

- Understanding and Analysis – Modelling
  - ubiquitous – analytical vs computational
- Design and Operation –
  - Simulators - routine but used fully?
  - Optimisation – specialised use only
  - Systems thinking?
- AI – How specialised should ChE be?
- Statistics – experimental analysis, handling big data?

# RiFTMaP and Smart Pharma Manufacturing

EPSRC and NSF: Sheffield, UCL, Strathclyde, Purdue

- To develop a systematic framework for smart continuous pharmaceutical manufacturing



The Diamond Pilot Plant  
at Sheffield University  
– wet granulation

Purdue Pilot Plant  
– dry granulation

# SEArCircularMINE Project

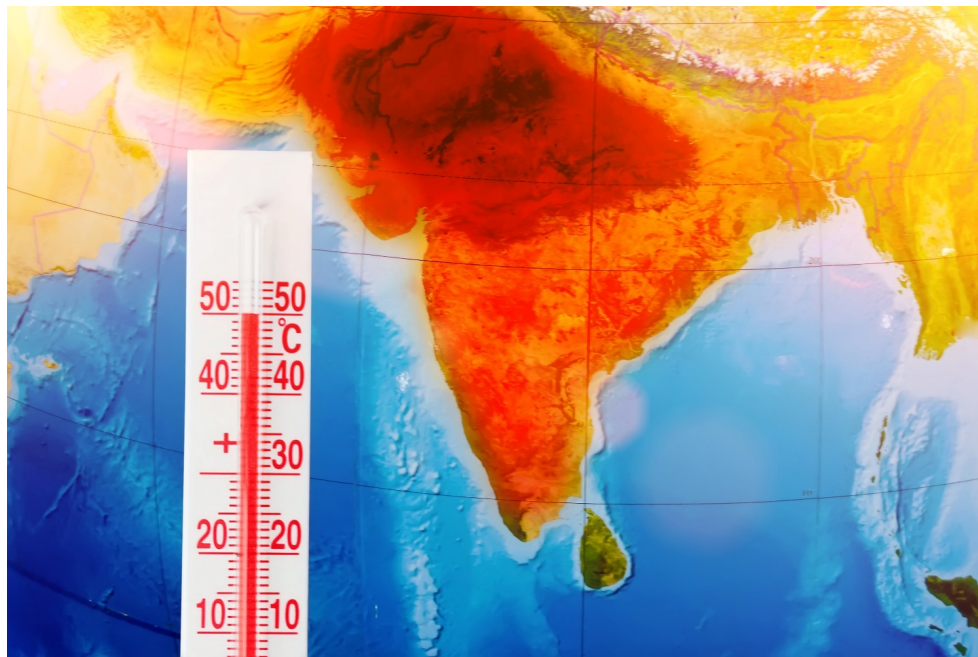


Circular Processing of Seawater Brines from Saltworks for Recovery of Valuable Raw Materials (EU Patent pending)

Co-Ordinator: Andrea Cipollina  
University of Palermo



# Sustainability - Chemical engineers are central to tackling the climate emergency



# Sustainability and Climate Change

- Energy mix
  - including nuclear and some use of fossil fuels
- Beyond Net Zero – carbon negative
- New feedstocks and energy sources
  - reduce energy but how do we get enough?
- Circularity and Systems Thinking. Accountability to society – accounting for every molecule?
  - ‘Make every penny count’ becomes ‘make every molecule count’.

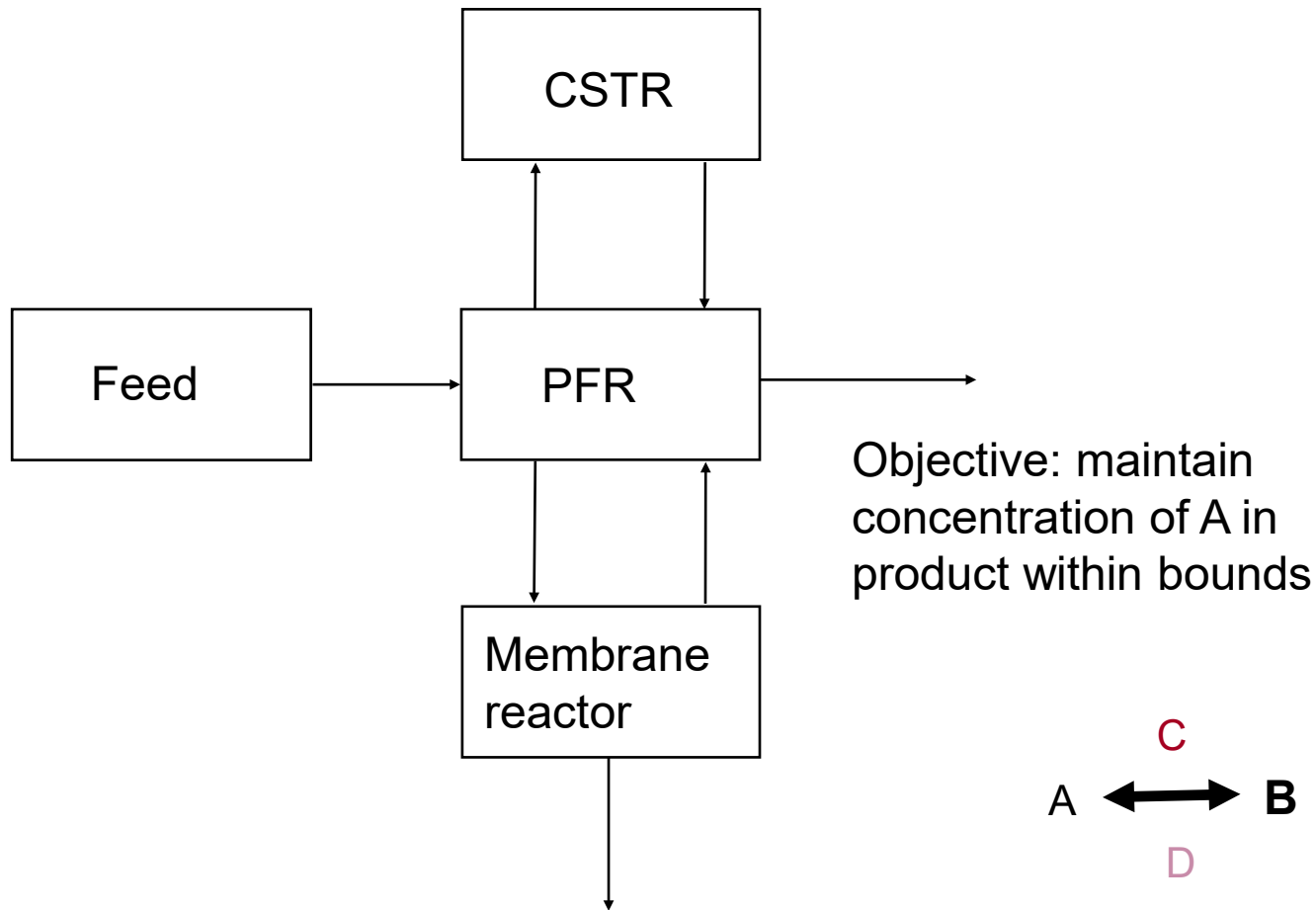
# Functional materials – design for function

- Recycled, repaired and reused
  - Self-assembling and self-healing materials
- Beyond the molecule and the mixture - Designing and making for function (textiles, coatings, synthetic human tissue...)

# Biology and Chemistry

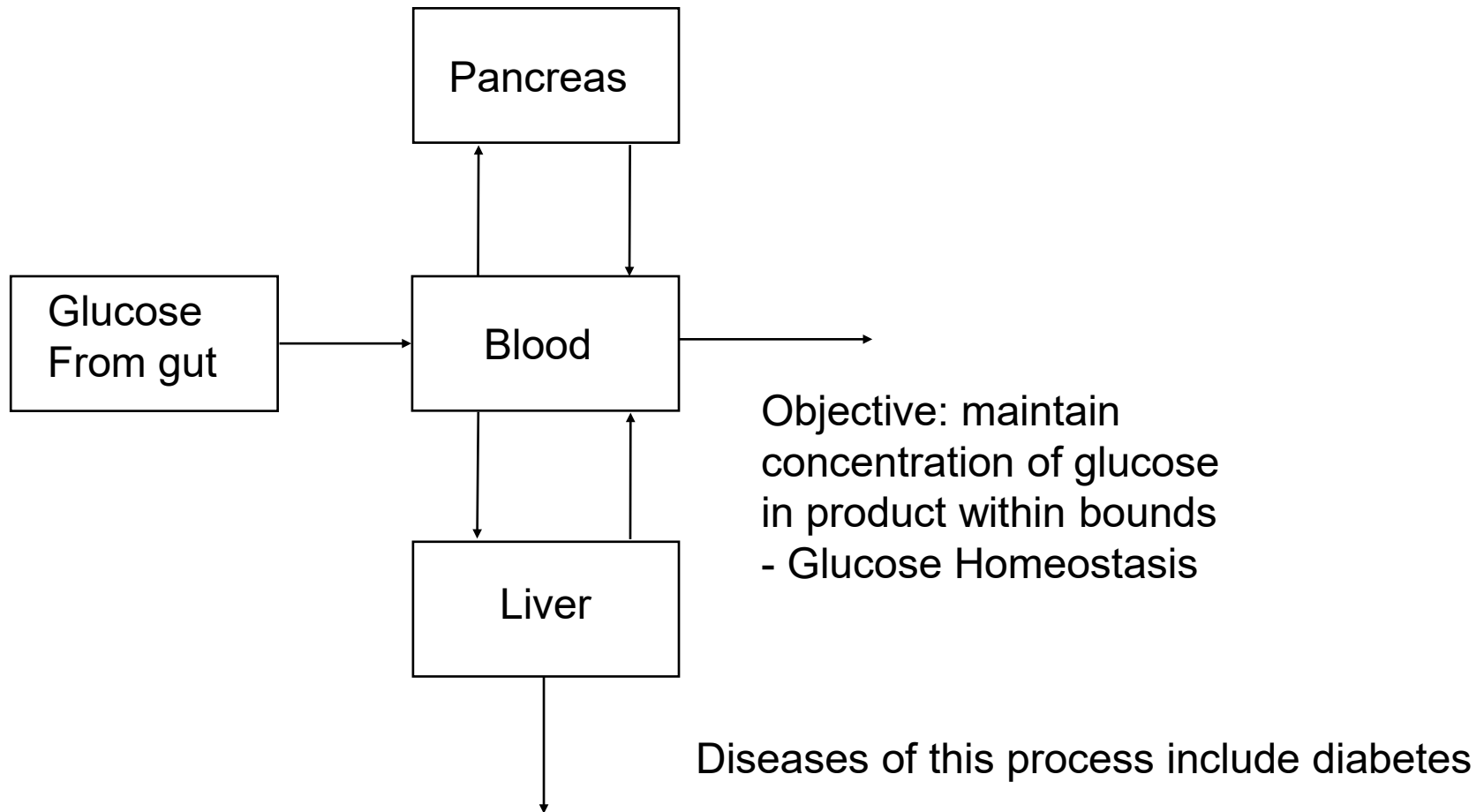
- 21<sup>st</sup> Century - The Century of Biology
- Merged manufacturing – changing regulation?
- Synthetic Biology
  - Synthetic genomes – eg for enhanced production
  - Designing DNA – use of AI to identify optimal genetic elements
  - Using whole cell simulations to design for functional performance
  - Biology as a manufacturing discipline

# A Process Flow Diagram



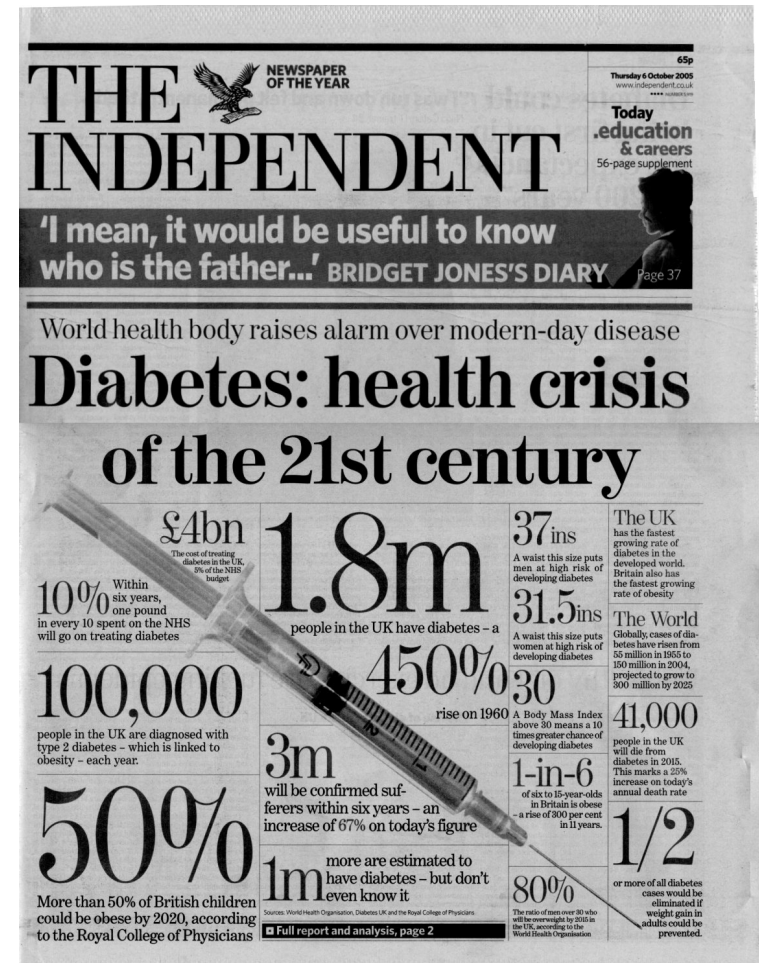


# A Process Flow Diagram – Glucose regulation



# The Liver as a Process System

- The liver performs many functions
  - Bile synthesis
  - detoxification ...
- We concentrate on glucose homeostasis
  - Medically important
  - Diabetes



**THE INDEPENDENT** NEWSPAPER OF THE YEAR  
 Thursday 4 October 2005 www.independent.co.uk  
 Today .education & careers 56-page supplement

**'I mean, it would be useful to know who is the father...'** BRIDGET JONES'S DIARY Page 37

World health body raises alarm over modern-day disease

## Diabetes: health crisis of the 21st century

**£4bn** The cost of treating diabetes in the UK, 9% of the NHS budget

**1.8m** people in the UK have diabetes - a **450%** rise since 1960

**100,000** people in the UK are diagnosed with type 2 diabetes - which is linked to obesity - each year.

**50%** More than 50% of British children could be obese by 2020, according to the Royal College of Physicians

**37 ins** A waist this size puts men at high risk of developing diabetes

**31.5 ins** A waist this size puts women at high risk of developing diabetes

**30** A Body Mass Index above 30 means a 10 times greater chance of developing diabetes

**3m** will be confirmed sufferers within six years - an increase of 67% on today's figure

**1m** more are estimated to have diabetes - but don't even know it

**1-in-6** of six to 11-year-olds in Britain is obese - a rise of 300 per cent in 11 years.

**80%** or more of all diabetes cases would be eliminated if weight gain in adults could be prevented.

**The UK** has the fastest growing rate of diabetes in the developed world. Britain also has the fastest growing rate of obesity

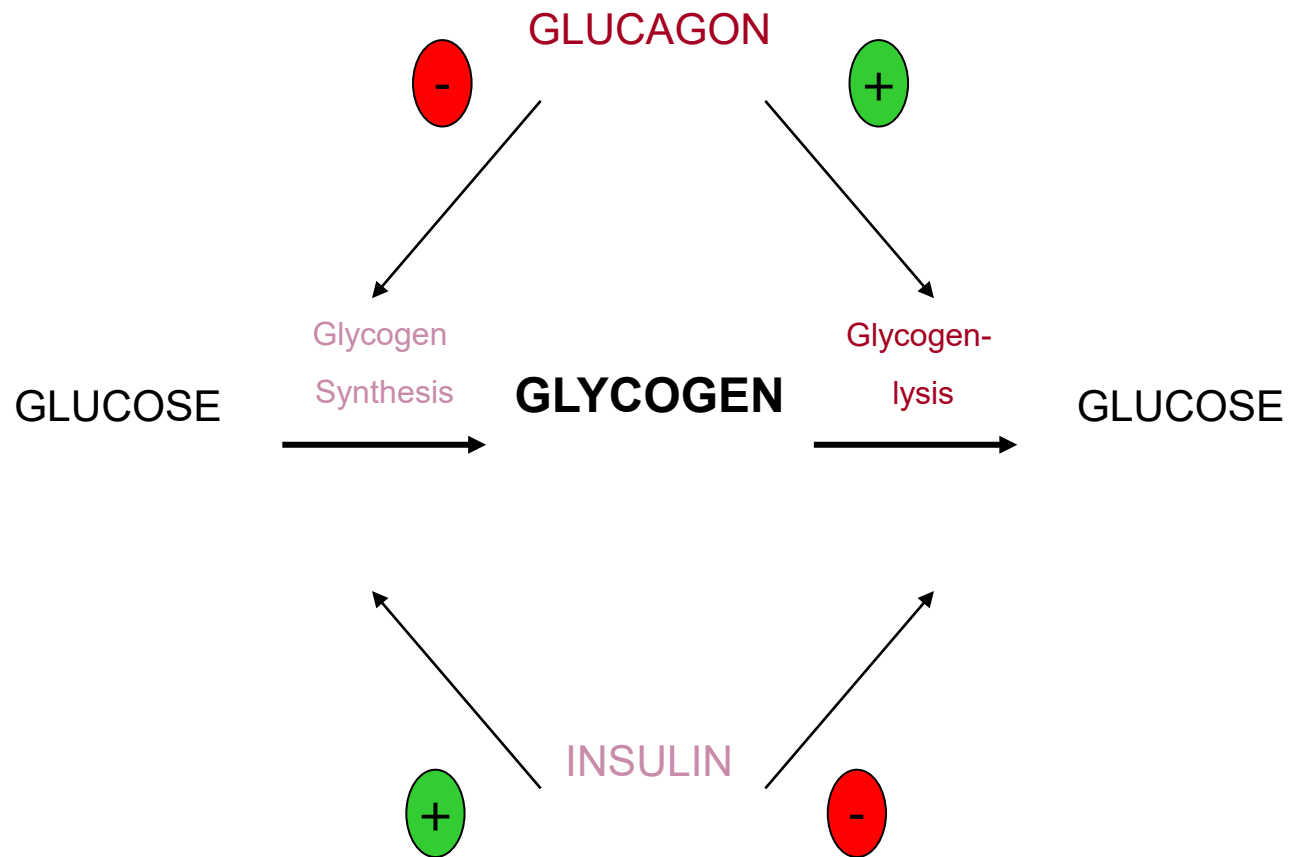
**The World** Globally, cases of diabetes have risen from 55 million in 1985 to 150 million in 2004, projected to grow to 300 million by 2025

**41,000** people in the UK will die from diabetes in 2015. This marks a 25% increase on today's annual death rate

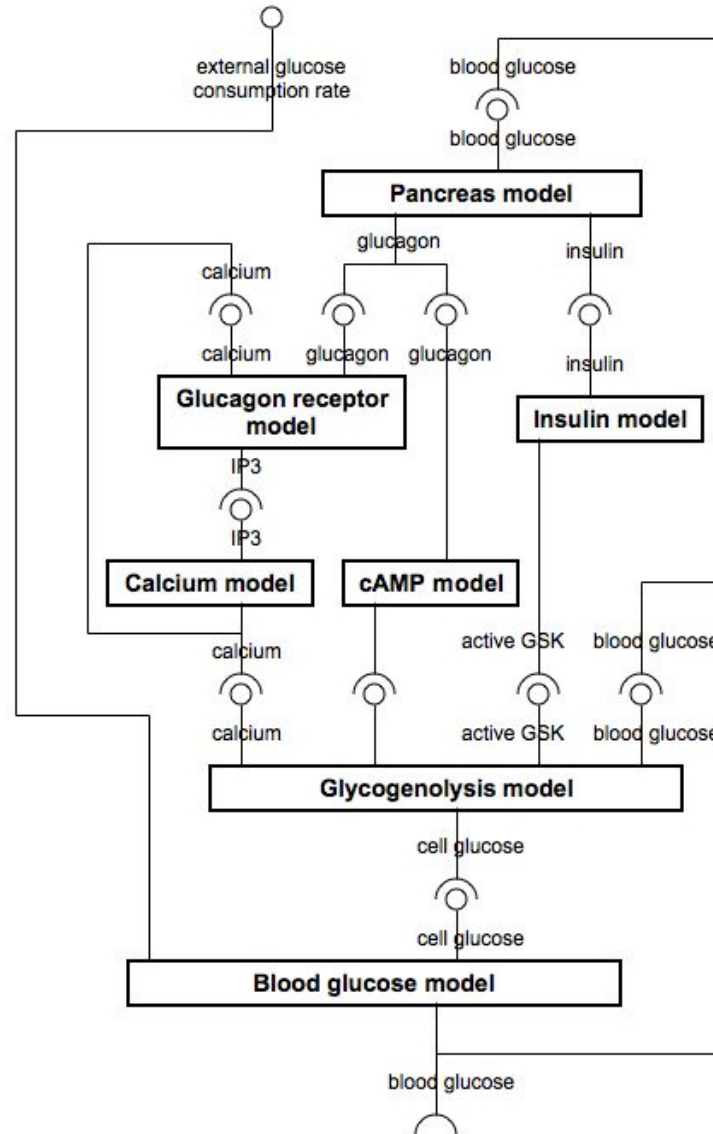
**1/2**

Sources: World Health Organisation, Diabetes UK and the Royal College of Physicians  
 Full report and analysis, page 2

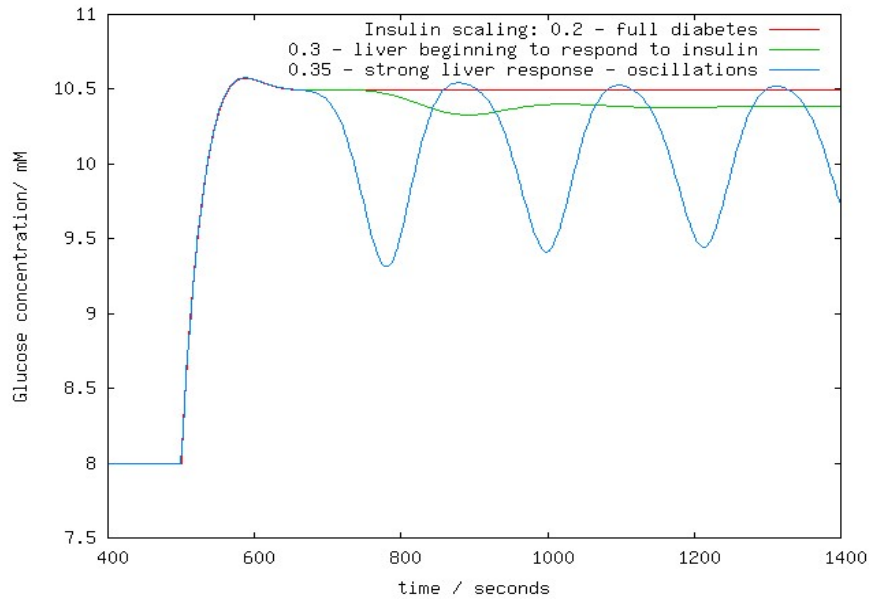
# Liver glucagon and insulin responses



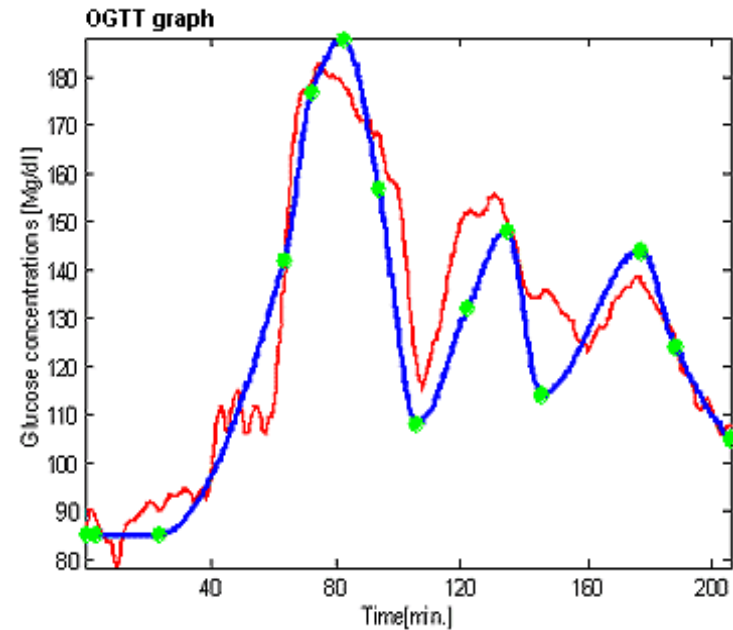
# The structure of the composite model



# Varying insulin sensitivity



Ultradian insulin oscillations - Existing models **focus on pancreas physiology.**

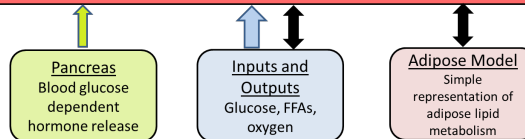
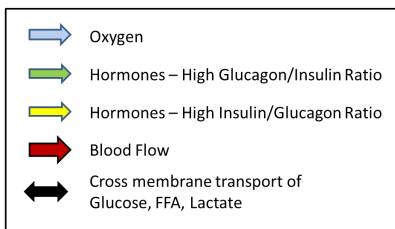
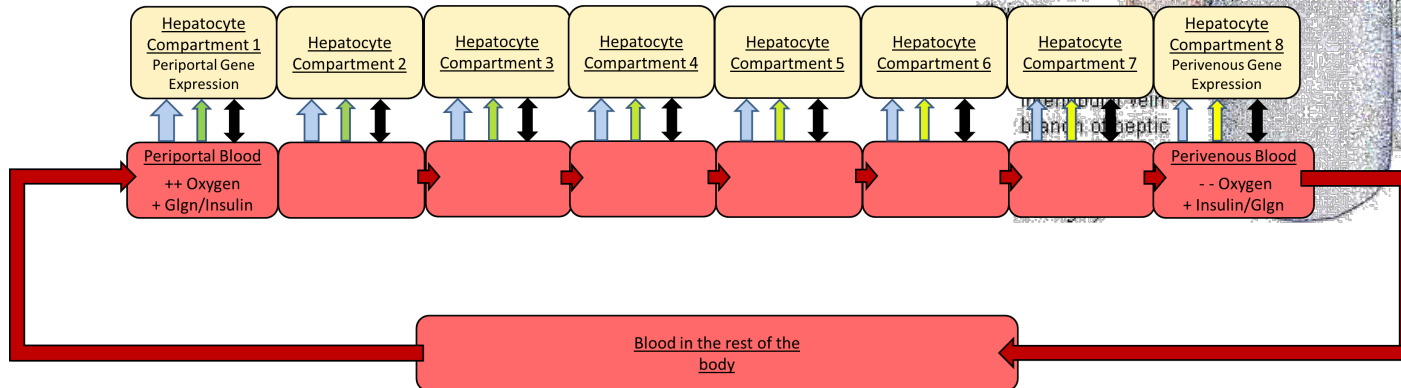
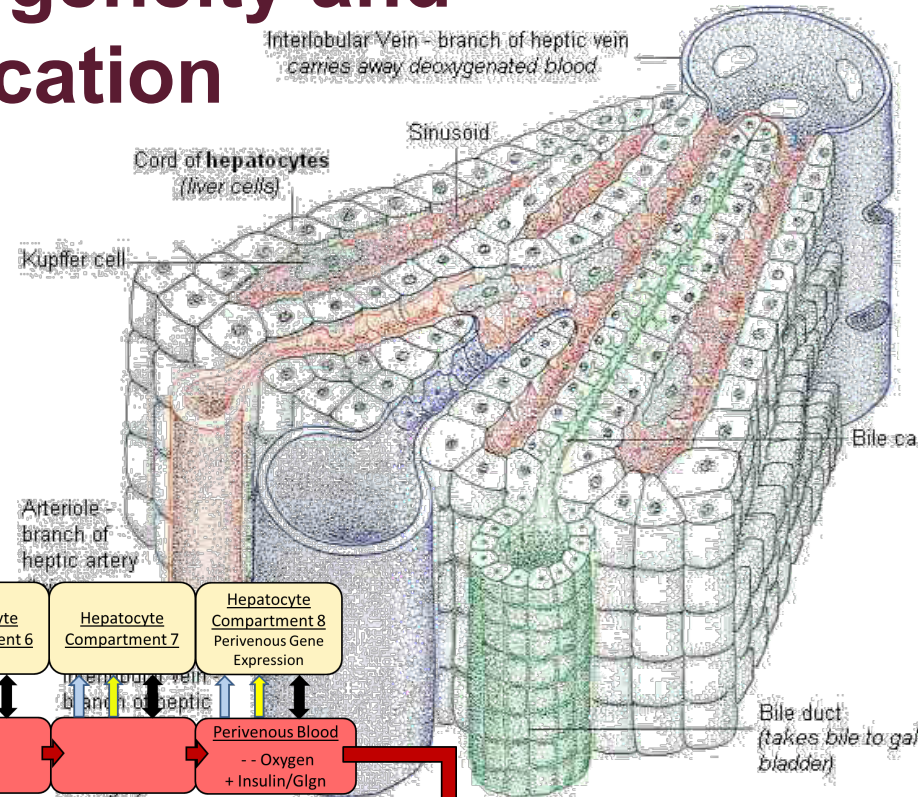


# Multicellularity, heterogeneity and intercellular communication

Hepatocytes vary

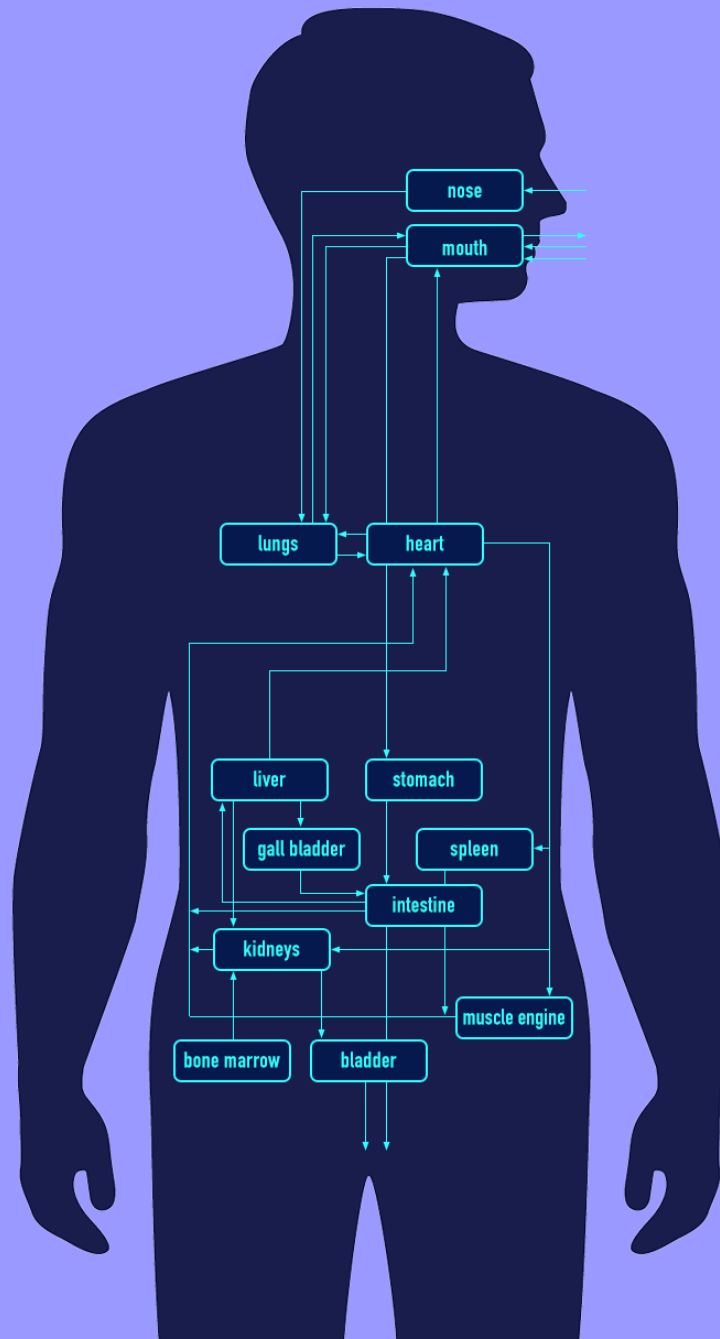
Hepatocytes communicate

- Through gap junctions
- **Junction amounts and types vary dynamically**



# Liver systems biology

- Liver not isolated, but works together with pancreas – systems thinking
- Cells not uniform across liver
- Wide variety of spatial and temporal scales involved
- Chemical, not electrical or mechanical



Model of the heart developed by Denis Noble (2005 Chem Eng World Congress)

New EFCE Section  
 ‘Chemical Engineering Applications in Medicine’



# A Chemical Engineering Contribution to Systems Biology and Medicine

- Modelling – quantification
- Complexity – Reaction and Transport
- Multiscale
  
- Understanding - Diagnosis
- Analysis - Prognosis
- ‘Design’ – Treatment
- Precision Personalised Medicine

**The future of Chemical Engineering is Bright..**

**aber/mais/pero/ale/but...**

# European Chemical Engineering Skills

<https://efce.info/Publications/Statements+and+White+Papers.html>

- Are we producing enough Chemical Engineers for the expanding scope?
- Do we have enough staff?
- Are we refreshing the staff pipeline fast enough?

# Chemical Engineering skills production data - some considerations

- Extent of industrial base
- Extent of recruitment of Chemical Engineers beyond traditional industries
- Different nature of courses
- Retention rates of students
- Accuracy of data

	Av. age of staff
Denmark	44
Slovenia	45
Sweden	45
UK	45
Spain	43-47
Lithuania	45.2
Croatia	46
Switzerland	46
Poland	46
Romania	46.2
Netherlands	48
Slovakia	49
Czech R	49.5
Germany	50
Portugal	53.4
Greece	54
Italy	55
Ukraine	57
France	N/A

	Student/staff ratio
Greece	17.4
Netherlands	17.4
Germany	17.4
Slovenia	17.1
UK	15.6
Croatia	15
Italy	13.8
Spain	12.9
Czech R	10.5
Sweden	9.6
Portugal	9.4
Poland	9.2
Romania	8.4
France	7.9
Switzerland	7.4
Slovakia	7
Denmark	6.6
Lithuania	6.2
Ukraine	2.4

	Grads per 100K population
Slovenia	7.3
UK	6.3
Netherlands	5.8
Czech R	5.3
Portugal	5.3
Spain	5.3
Germany	4.9
Croatia	4.2
Romania	3.9
Switzerland	3.3
Denmark	3.1
Poland	2.9
Slovakia	2.5
France	2.3
Italy	2.3
Sweden	2.1
Lithuania	1.9
Greece	1.2
Ukraine	0.17

	Grads per 1000 Chemical Industry
Portugal	38.7
Romania	34.2
UK	27.5
Netherlands	17.1
Denmark	16
Spain	12.7
Italy	12.5
Greece	10
France	9.3
Germany	8.8
Lithuania	8.7
Slovenia	4.8
Czech R	4.2
Sweden	3.9
Switzerland	3.7
Poland	3.5
Croatia	3
Slovakia	1.1
Ukraine	N/A

# Investing in Chemical Engineering Skills

- Significant variation
- Making the case for national investment - figures are useful to support the case
- Are there enough for the growing breadth of the discipline?

# Chemical Engineering researcher careers - should I postdoc?

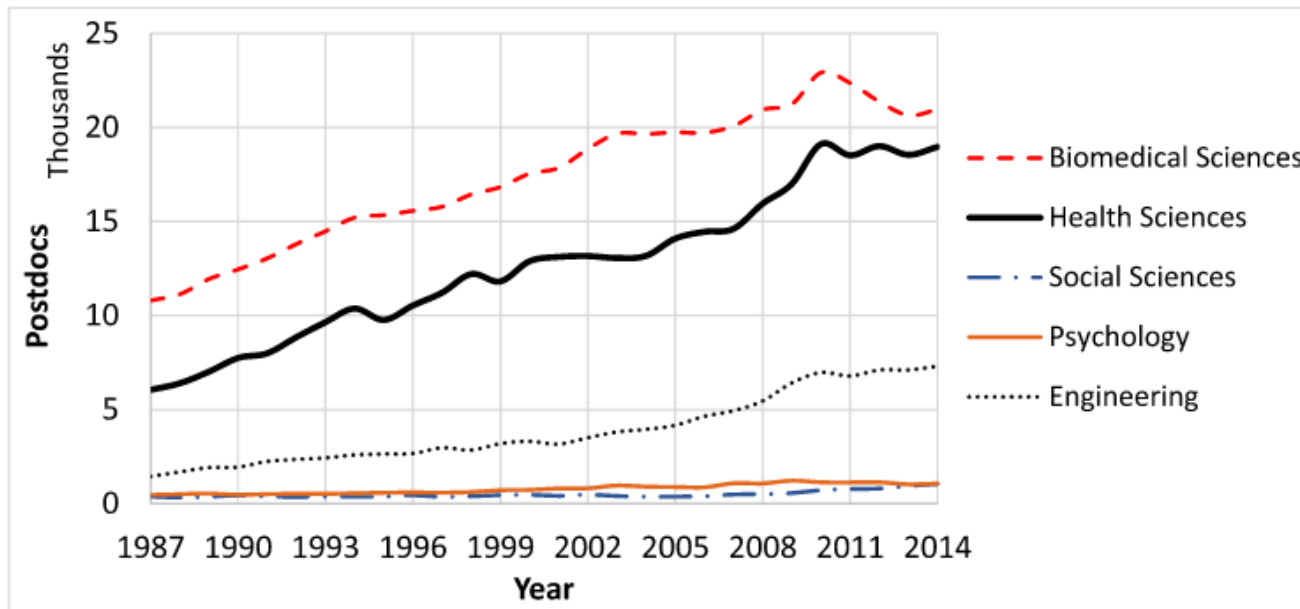


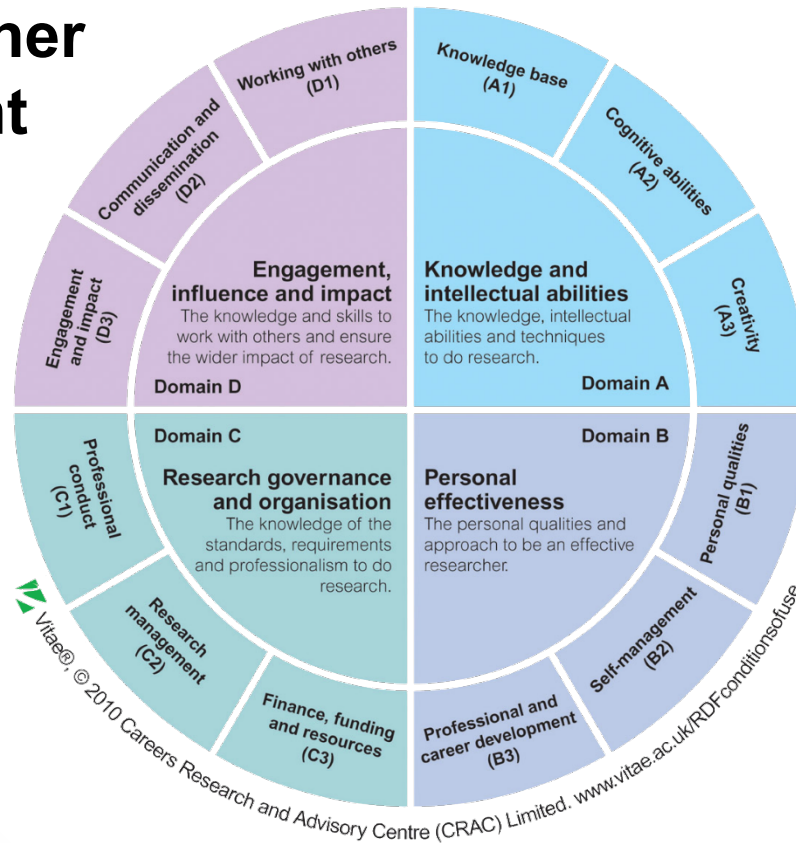
Figure 1 Number of postdocs in the US by major field 1987–2014. Data source: Survey of Doctorate Recipients (National Science Foundation, 2015). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



# Chemical Engineering researcher careers

- Researchers as Drivers of Innovation in society: training 'creative critical autonomous responsible intellectual risk takers'
- To academia or not to academia?
- Should I postdoc?
- Some benefits of industrial experience
  - Gives a range of experience
  - Grounding knowledge in practice
  - Making career decisions later

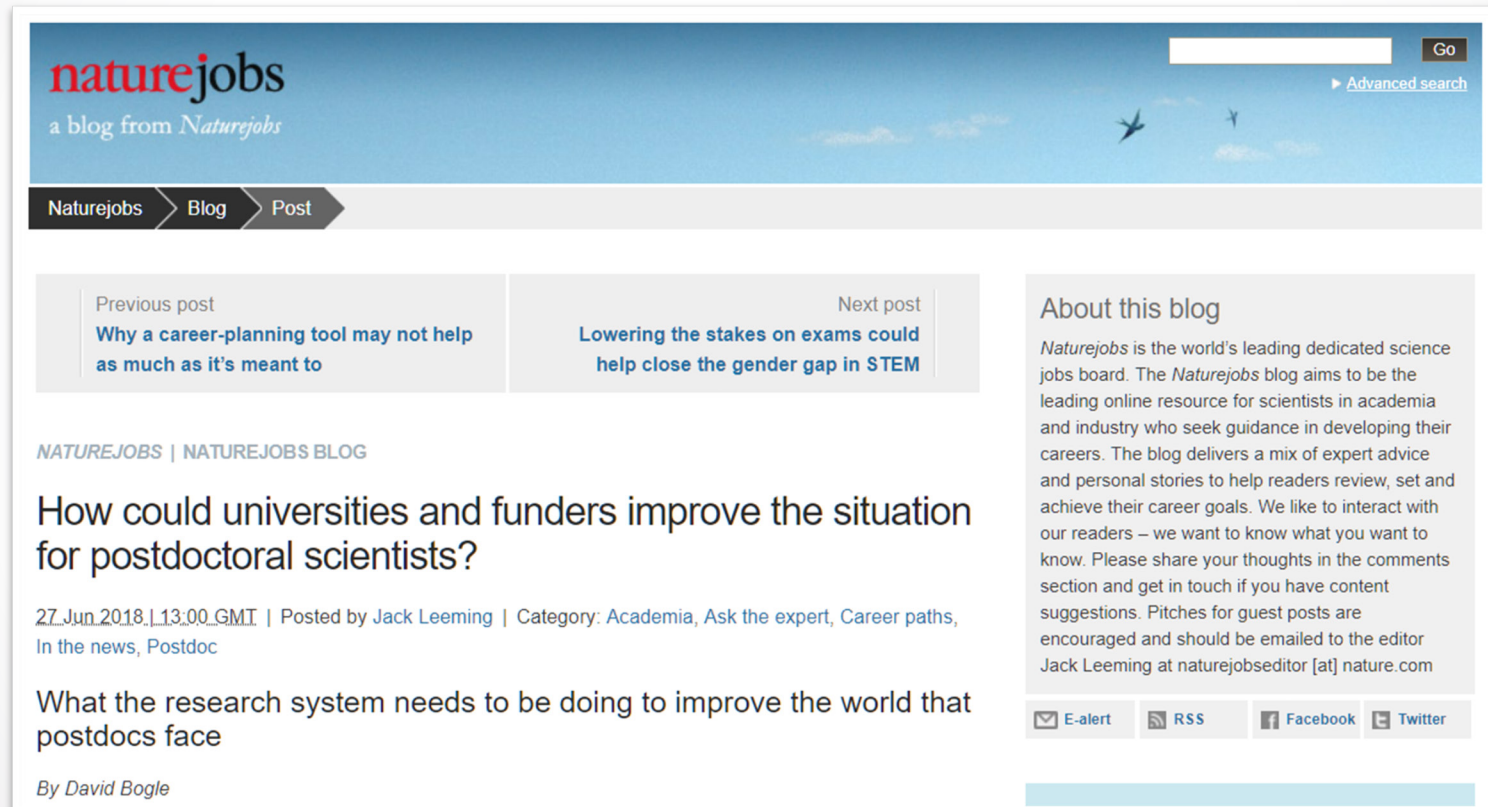
# UK Researcher Development Framework



A structure for developing skills as a researcher

## Should I postdoc? What is a postdoc for? What experience is useful?

# Skills to be acquired as a postdoc



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a blog from *Naturejobs*

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**NATUREJOBS | NATUREJOBS BLOG**

### How could universities and funders improve the situation for postdoctoral scientists?

27 Jun 2018, 13:00 GMT | Posted by [Jack Leeming](#) | Category: [Academia](#), [Ask the expert](#), [Career paths](#), [In the news](#), [Postdoc](#)

What the research system needs to be doing to improve the world that postdocs face

By *David Bogle*

**About this blog**  
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<http://blogs.nature.com/naturejobs/2018/06/27/how-could-universities-and-funders-improve-the-situation-for-postdoctoral-scientists/>

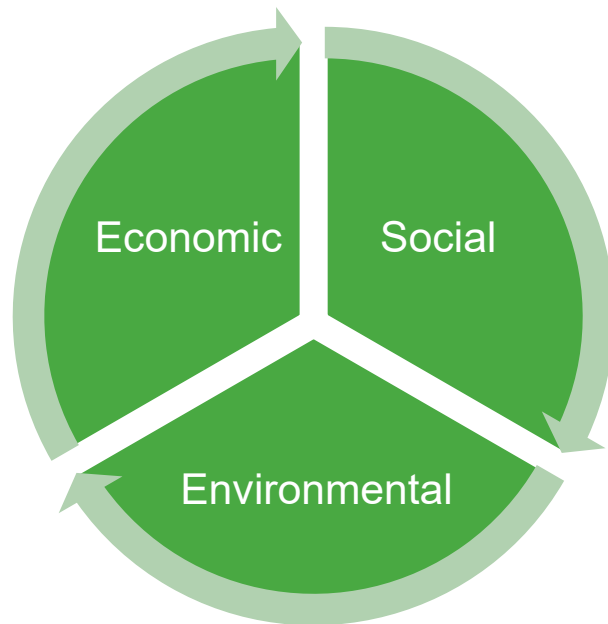
## Research vs innovation

- Innovation ‘the act or process of introducing new ideas, devices, or methods’
- **Training also for innovation:** take new ideas (one’s own or others’) forward in order to make an impact in small and large organisations and in society more generally (beyond ‘entrepreneurship’...)

# Professionalism in the curriculum

- Technical topics – how broad should we be?
  - Health and Safety
  - Sustainability
  - Ethics?
- 
- Ensuring questioning, challenging, innovating, rigour, ethical reflection

# Sustainability Challenge

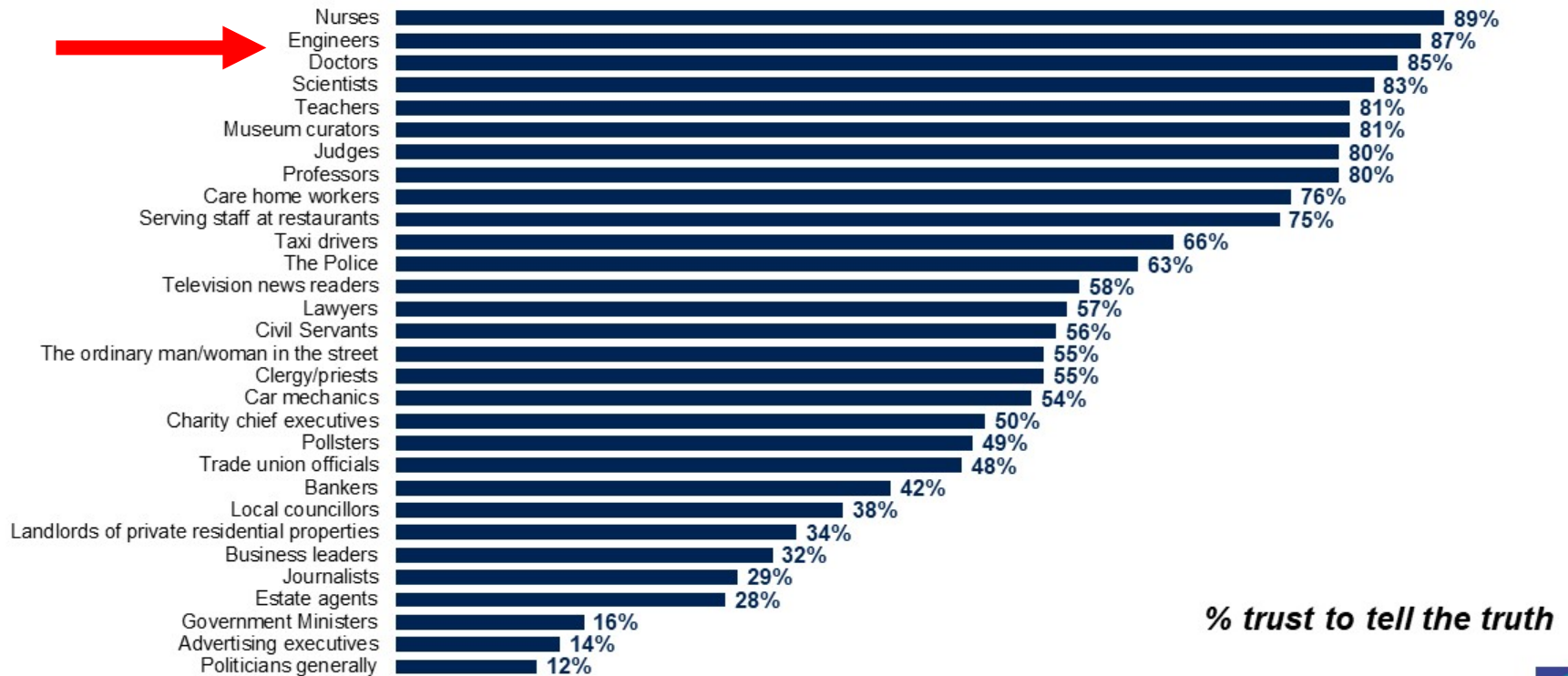


## Some examples – asking ‘so what?’ What is the Social impact on stakeholders?

- Help clarify the debate about ethical energy policies
- What are the consequences of CCS and CCU investment?
- Highlight the effect of uncertainty on emissions and safety
- How tight should safety and sustainability constraints be to satisfy all stakeholders?

# Veracity Index 2022 – all professions

“Now I will read you a list of different types of people. For each would you tell me if you generally trust them to tell the truth, or not?”



Base: 1,005 and 1,004 British adults aged 16+, interviewed by telephone 19 – 26 October and 26 October – 1 November

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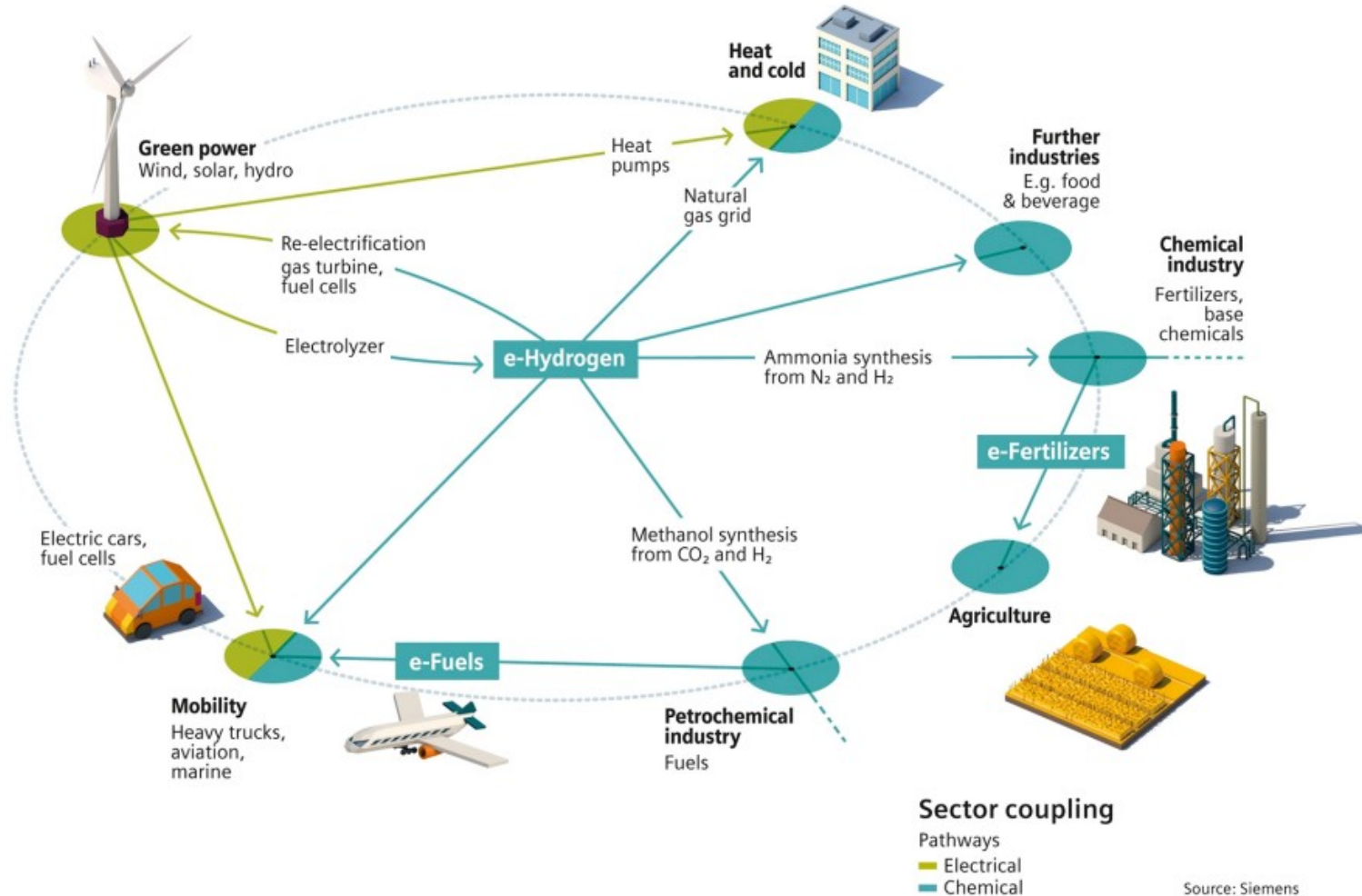
Greater societal scrutiny on engineering decisions...



# What would good engineering ethics look like?

- All those in the engineering profession act with:
  - Honesty and integrity
  - Respect for life, law, the environment and public good
  - Accuracy and rigour
  - Leadership and communication
- Engineers remain among most trusted of professionals
  - Public trust in **and awareness of** the engineering profession remains continuously high
- Internationally recognised as having high ethical standards in engineering
- **All apprentices and students explore ethical decision making (as we do health & safety and sustainability)**

# Systems Thinking - a powerful strength



# Systems Thinking - a powerful strength

- Design and systems teaching
- LCA – of whole supply chains and systems
- Circular economy
- Involving stakeholder views
- Scenarios for policy formulation
  
- Are these sufficiently central in our training?

## Future challenges

- Responsiveness of the supply chain
- Climate emergency
- Infrastructure and systems
- Designing new materials for function
- Personalized medicine
  
- Many challenges are cross-disciplinary

# Softening disciplinary boundaries or breaking them?

- Teaching and curricula – greater choice
- Accreditation
  - Safety, Sustainability and Ethics
  - Collaboration with other engineers, scientists and social scientists
- Interdisciplinary research – from strong disciplinary base

## Challenges (in summary) – some questions

- Are we producing enough Chemical Engineers and investing enough in their education?
- Is researcher development adequate?
- Are we embedding ethical thinking?
- Is Systems Thinking central everywhere?

# Conclusions

- What is Chemical Engineering today? The Engineering of Chemicals...
  - Producing systems thinkers
  - A collaborative discipline
- Sustainability at the heart - making the public more aware of our role and more attractive as a career to young people

# Thanks

- To the EFCE for honoring me with this award
- To many colleagues at UCL, Imperial College, Universities of Palermo, Sheffield, Strathclyde, Purdue, Adelaide, many industrial collaborators, EFCE, Royal Academy of Engineering, Engineering Council, IChemE
- To you for listening