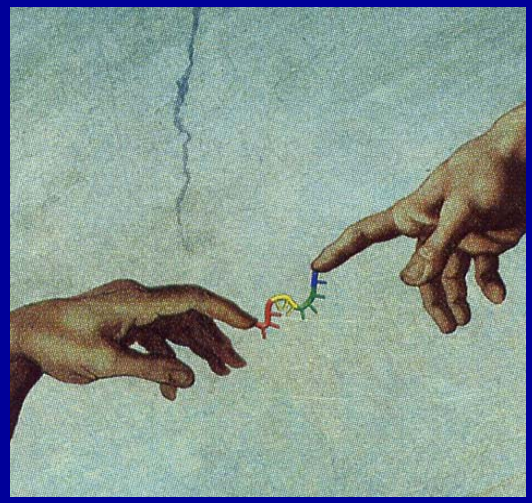
**Imperial College London**

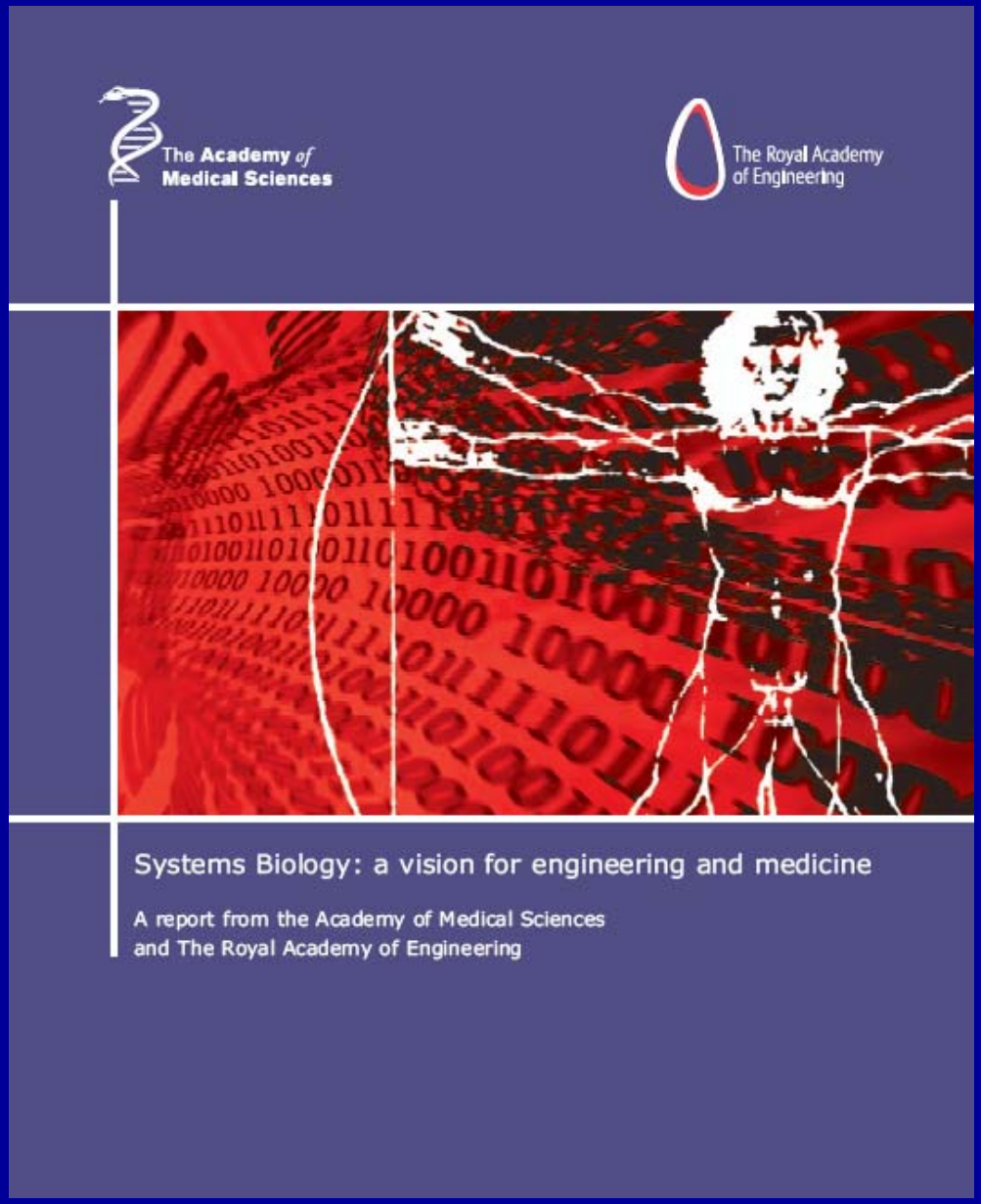


# Synthetic Biology – State, Importance and Development

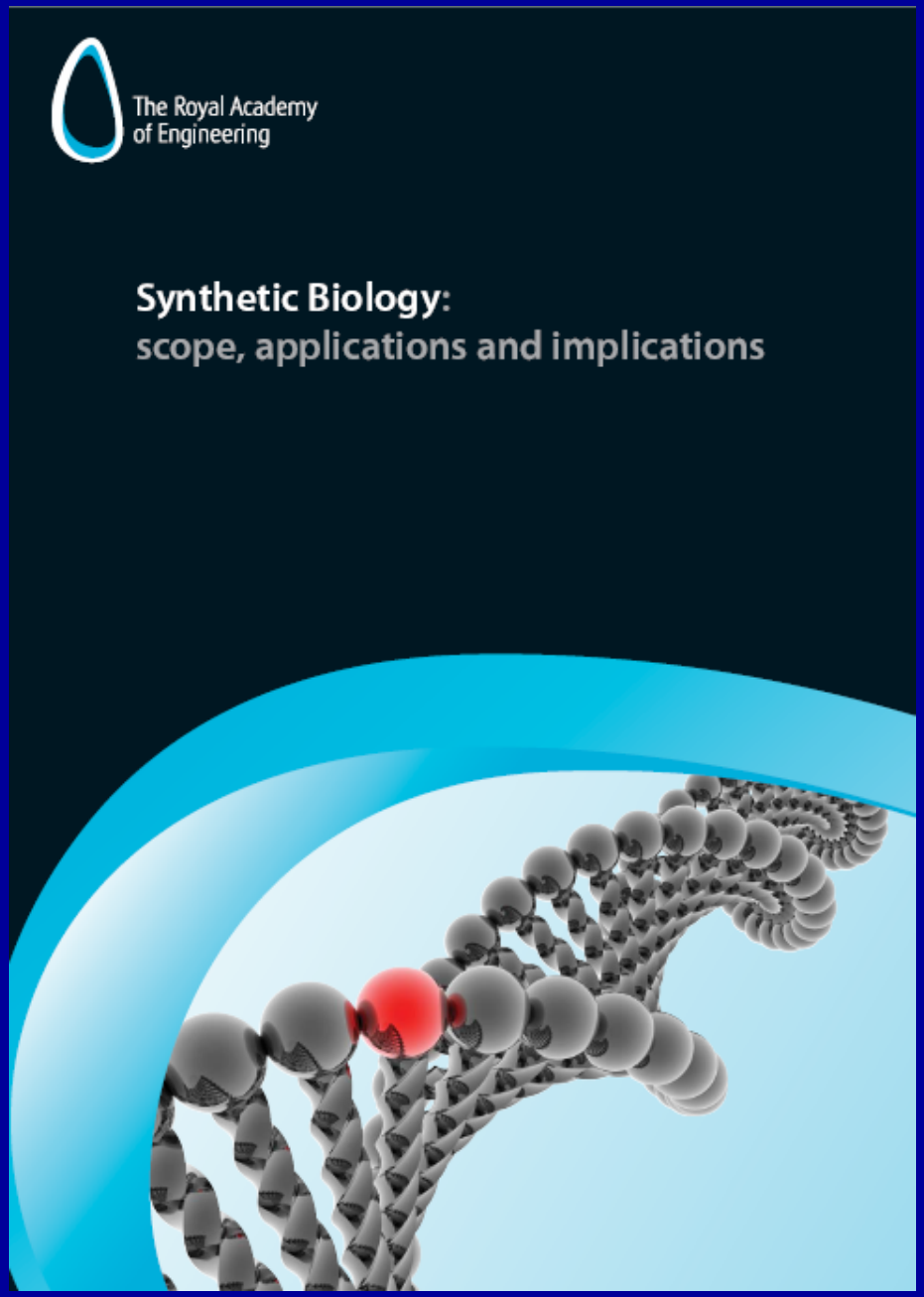
Professor Richard I Kitney

Chairman - The Institute of Systems and Synthetic Biology

Co-director – Centre for Synthetic Biology and Innovation




http://www.raeng.org.uk/policy/engagement/pdf/Systems_Biology_Report.pdf




http://www.raeng.org.uk/news/publications/list/reports/Synthetic_biology.pdf

# Synthetic Biology

# What is Synthetic Biology?

- Designing and making biological parts and systems that do not exist in the natural world using engineering principles

- Re-designing existing biological systems, again using engineering principles

# Why now?

# Why now?

- High speed DNA sequencing
- DNA synthesis
- Powerful computers
- Broadband networks
- The Internet
- The confluence of biology, engineering and physical science

# Key Points

The endpoint of Synthetic Biology is industrialisation

The endpoint of analysing biological systems is Systems Biology

# Synthetic Biology

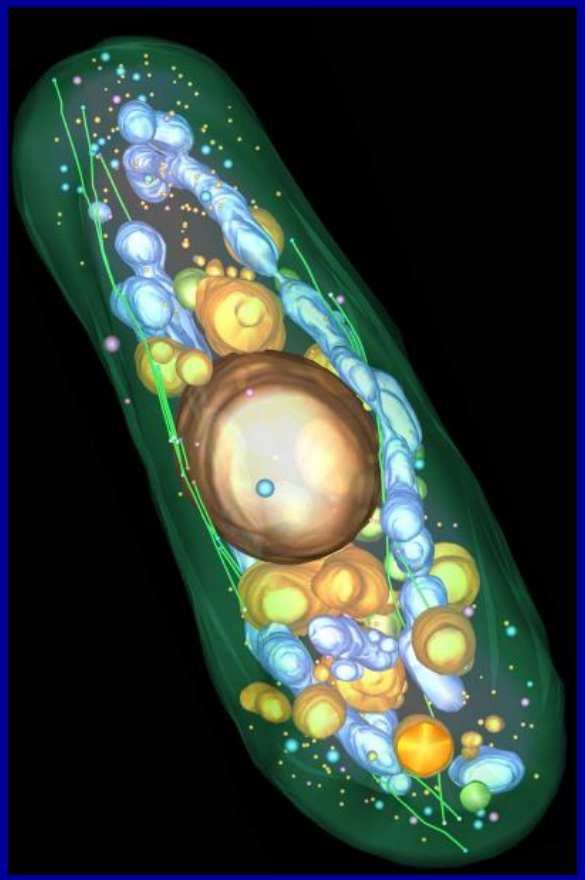
A Broad Church

- Bio nanotechnology
- Synthetic genomics
- Engineering

With Social Science and Ethics integrated part of the field

# Four Approaches to Synthetic Biology

- Bottom Up
- Metabolic Engineering
- Chassis
- Parts, Devices and Systems



# 1. Bottom Up

Article Views
Abstract
Full Text (HTML)
Full Text (PDF)
Figures Only
Supporting Online Material
VERSION HISTORY
319/5867/1215 (most recent)
1151721v1
Article Tools
Save to My Folders
Download Citation
Alert Me When

Originally published in *Science* Express on 24 January 2008
*Science* 29 February 2008:
Vol. 319. no. 5867, pp. 1215 - 1220
DOI: 10.1126/science.1151721

‹ Prev | Table of Contents | Next ›

ADVERTISEMENT
Renew or Subscribe Today!
CLICK HERE
Science Signaling
ADVERTISEMENT
Submit

RESEARCH ARTICLES

# Complete Chemical Synthesis, Assembly, and Cloning of a *Mycoplasma genitalium* Genome

**Daniel G. Gibson, Gwynedd A. Benders, Cynthia Andrews-Pfannkoch, Evgeniya A. Denisova, Holly Baden-Tillson, Jayshree Zaveri, Timothy B. Stockwell, Anushka Brownley, David W. Thomas, Mikkel A. Algire, Chuck Merryman, Lei Young, Vladimir N. Noskov, John I. Glass, J. Craig Venter, Clyde A. Hutchison, III, Hamilton O. Smith***

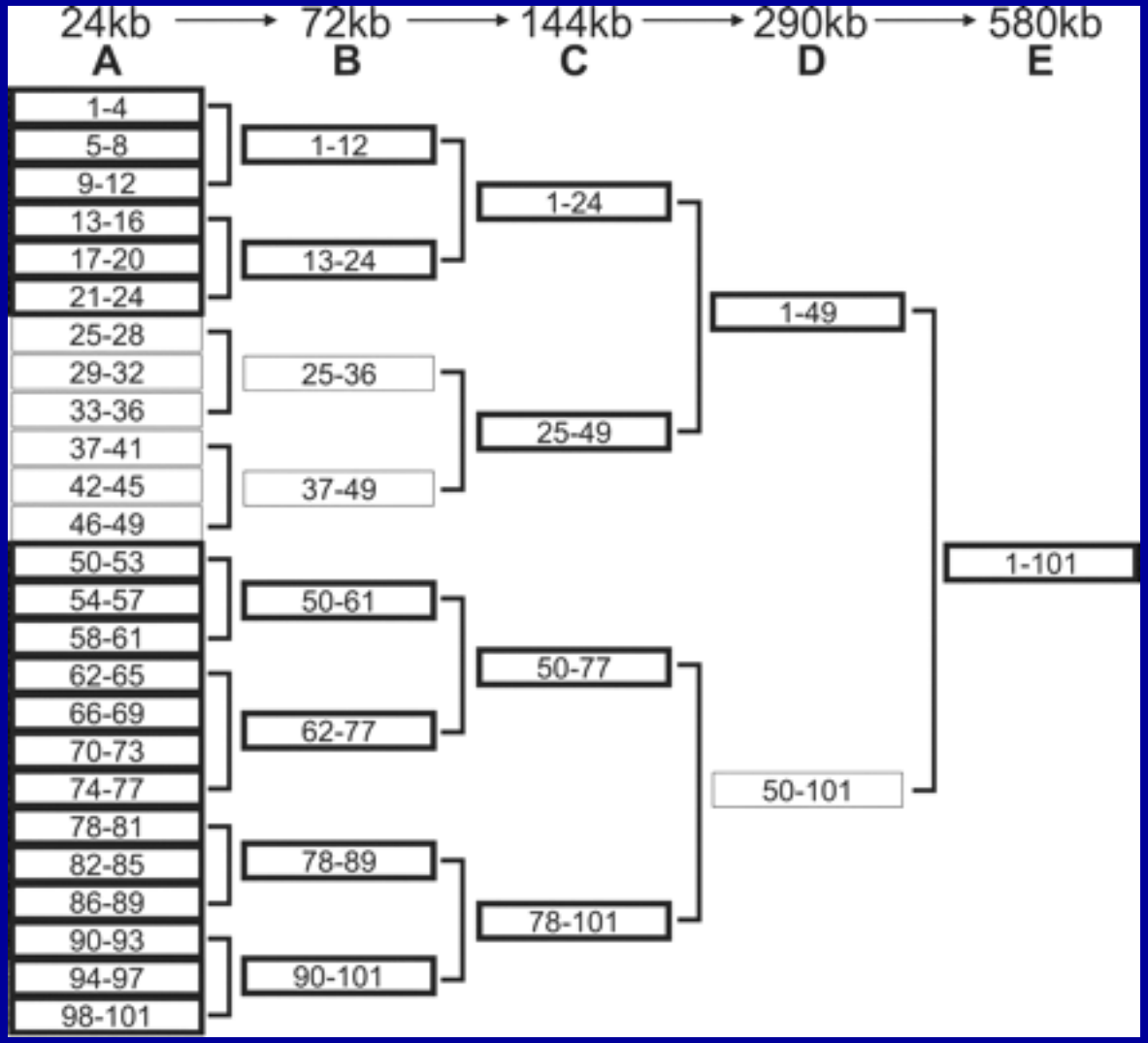
We have synthesized a 582,970–base pair *Mycoplasma genitalium* genome. This synthetic genome, named *M. genitalium* JCVI-1.0, contains all the genes of wild-type *M. genitalium* G37 except MG408, which was disrupted by an antibiotic marker to block pathogenicity and to allow for selection. To identify the genome as synthetic, we inserted "watermarks" at intergenic sites known to tolerate transposon insertions. Overlapping "cassettes" of 5 to 7 kilobases (kb), assembled from chemically synthesized oligonucleotides, were joined by in

# Steps in the synthesis of a 583kbp M.Genitalium Genome

1. Overlapping “cassettes” of 5 to 7 kb were assembled from chemically synthesised oligonucleotides

2 Joined *in vitro* to produce intermediate assemblies of approximately 24kb, 72kb (1/8 genome) and 148kb (1/4 genome) – all cloned as bacterial artificial chromosomes (BACs) in E. coli

3. The complete synthetic genome was assembled using transformation associated recombination (TAR) cloning in yeast




BLUEHERON® BIOTECHNOLOGY

GENEART THE GENE OF YOUR CHOICE

DNA 2.0

# 2. Metabolic Engineering

# Malaria

# Artemisia

- Used by Chinese herbalists for more than 1000 years to treat Malaria
- 1972 - Tu Youyou discovered artemisinin in the leaves of the Artemisia Annua (annual wormwood)

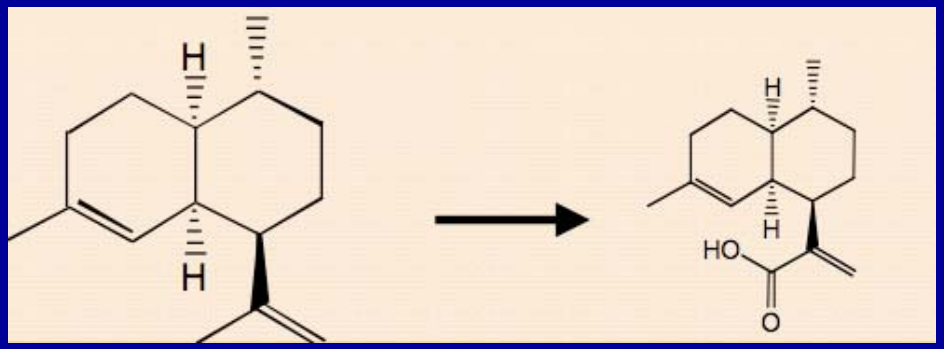
**Tu Youyou 屠呦呦** [sources / revisions]

**Chief Research Fellow of the Institute of Chinese Traditional Medicines at the Chinese Academy of Traditional Chinese Medicine**

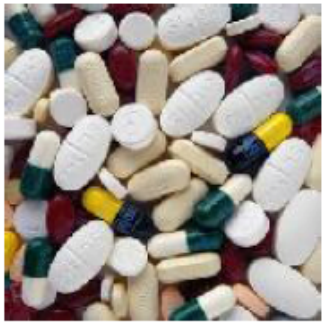
**Born:** 1930

# Making Complex Drugs

## Anti-malarial drug Artemesinin




Amyris Biotechnologies



Institute for OneWorld Health

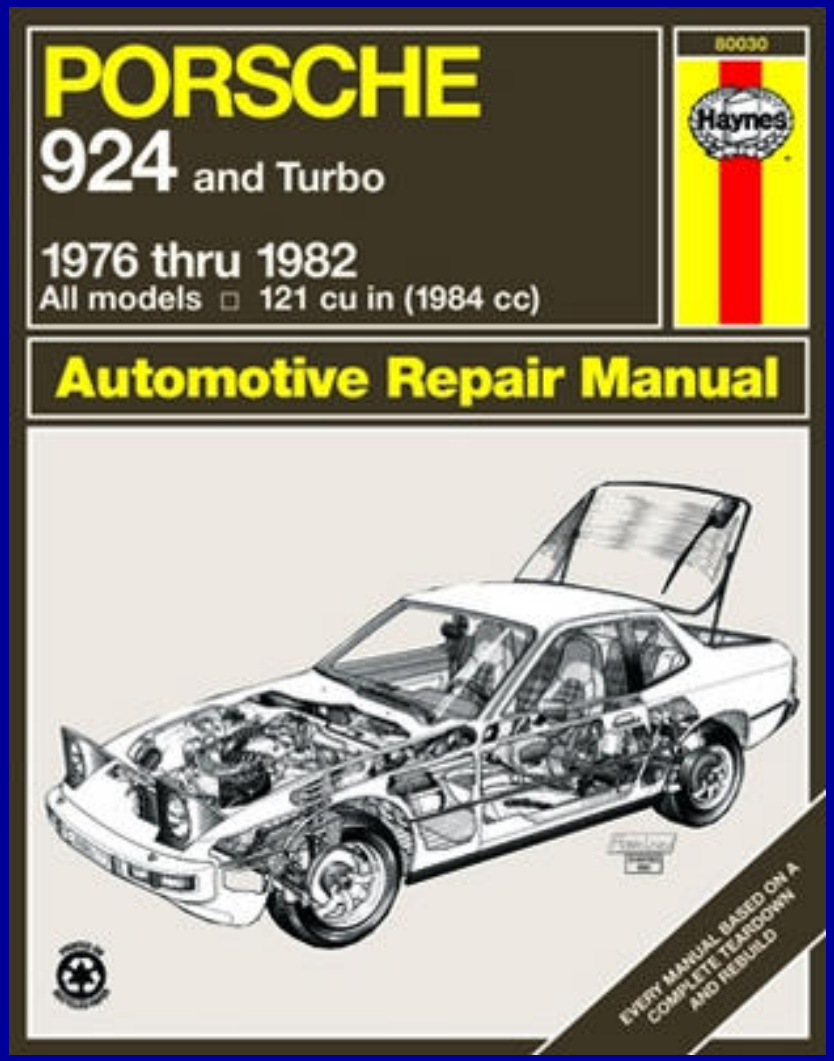
# 3. Chassis

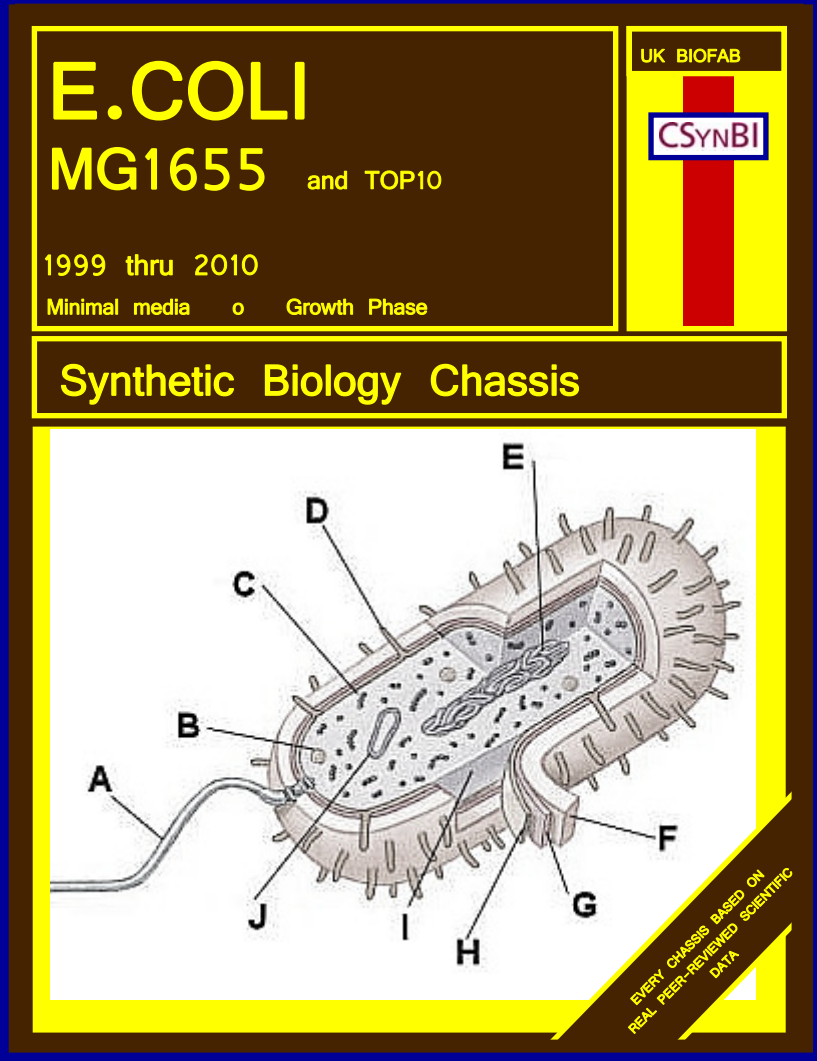
# Chassis

- Natural Chassis
  - E. Coli
  - B. Subtilis
  - Mycoplasma
  - Yeast
  - P. putida
- Minimal Cells
  - achieving control

# Developing chassis that are fit for purpose

# Chassis for Synthetic Biology



# 1st Generation Synthetic Biology

## E.COLI
MG1655 and TOP10

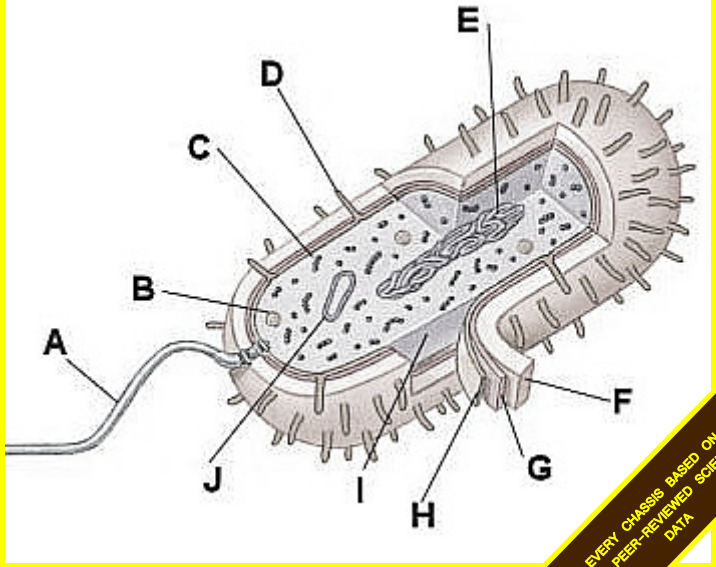
1999 thru 2010

Minimal media o Growth Phase

UK BIOFAB

CSynBI

Synthetic Biology Chassis




EVERY CHASSIS BASED ON REAL PEER-REVIEWED SCIENTIFIC DATA

## YEAST
S.CEREVISIAE

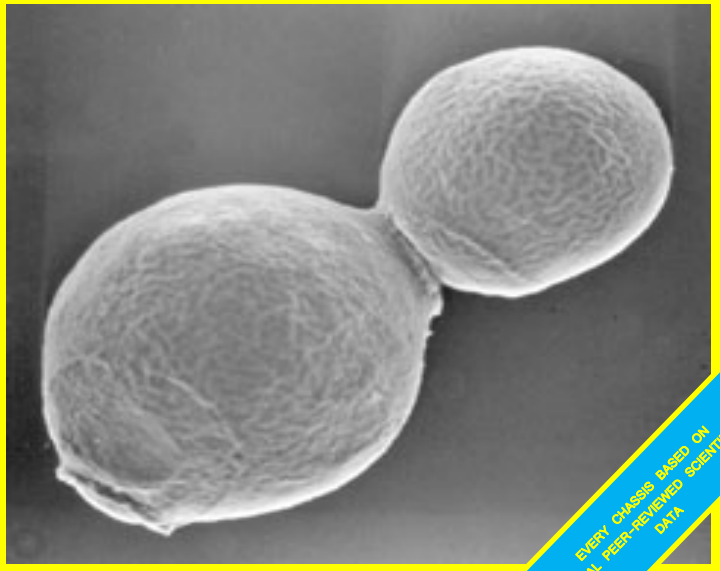
2002 thru 2010

Synthetic Defined Media o Growth Phase

UK BIOFAB

CSynBI

Synthetic Biology Chassis



EVERY CHASSIS BASED ON REAL PEER-REVIEWED SCIENTIFIC DATA

# 2nd Generation Synthetic Biology

## B.SUBTILIS

**Gram Positive**

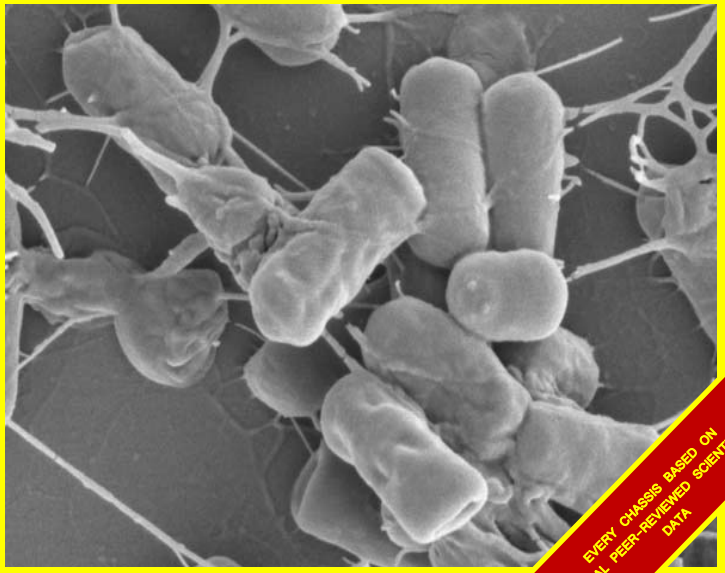
2006 thru 2010

Sporulation-capable o Growth Phase

UK BIOFAB

CSynBI

Synthetic Biology Chassis



EVERY CHASSIS BASED ON REAL PEER-REVIEWED SCIENTIFIC DATA

## CHO-K1

**Mammalian**

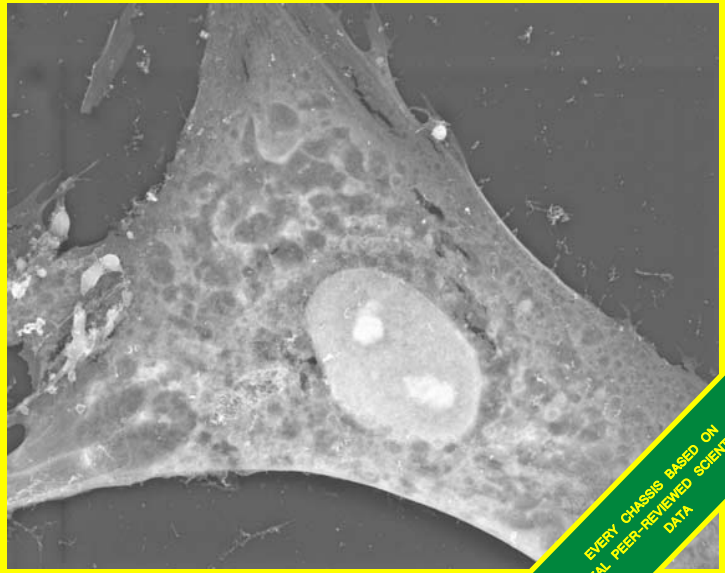
2004 thru 2010

Immortal Cell Line o DMEM Media

UK BIOFAB

CSynBI

Synthetic Biology Chassis



EVERY CHASSIS BASED ON REAL PEER-REVIEWED SCIENTIFIC DATA

# Relevance of Current Chassis

| | |
|---|---|
| *E.coli* | Advanced molecular cloning<br>Industrial-scale application |
| *B.subtilis* | Commonly used in industry<br>Well-understood genetic regulation |
| *S.cerevisiae* | Major industrial organism<br>Extensively characterised |
| CHO-K1 cells<br>(+ others) | Easy to use immortal mammalian cell line<br>Good transfection efficiency |

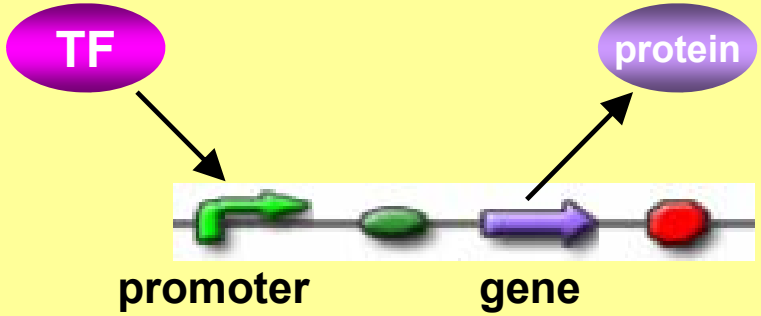
Industrial-scale biosynthesis

Ease of re-engineering

# 4. Parts, Devices and Systems

# Engineering v Biology

## Modularity, Characterisation, Standardisation




**Typical gene transcription module**

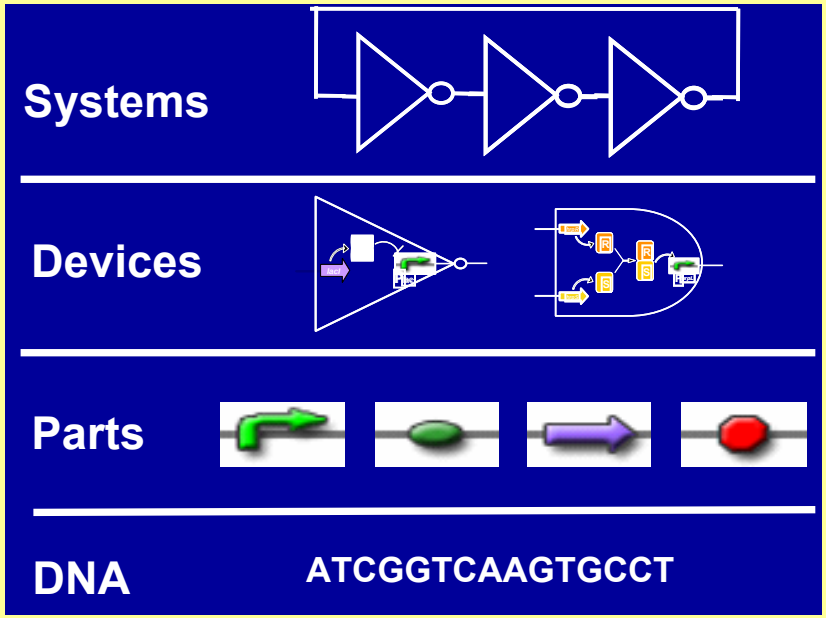

Ribosome binding site


Protein coding sequence


Terminator

Transcription factor

**A hierarchy for synthetic biology**



# Systematic Design

The basis of all engineering - parts, devices and systems

# The Engineering Approach to Design

- Abstraction
- Decoupling
- Standardisation

# The Engineering Approach to Design in Synthetic Biology

Engineering systems are built from a hierarchy

- Parts
- Devices
- System


- At each level the characteristics of the Part, Device or System are well defined and reproducible

- In engineering the aim is to build a system on the basis of devices which comprise standard parts

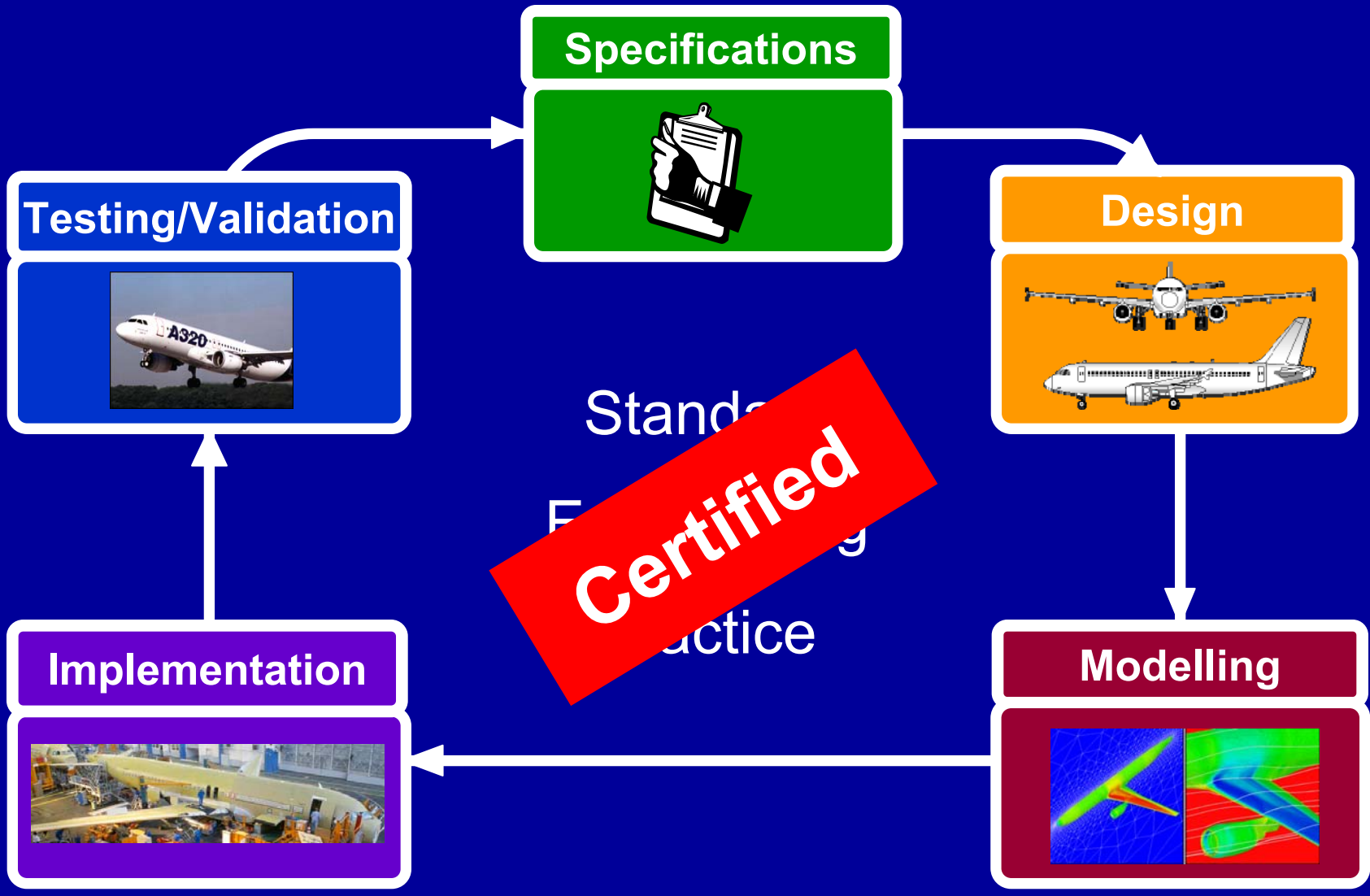
# Synthetic Biology: aims to build applications from Biobricks

- Parts – encode biological functions (ie often modified DNA)
- Devices – made from a collection of parts and encode human-defined functions (eg logic gates)
- Systems – perform tasks, eg counting

# Engineering Biology

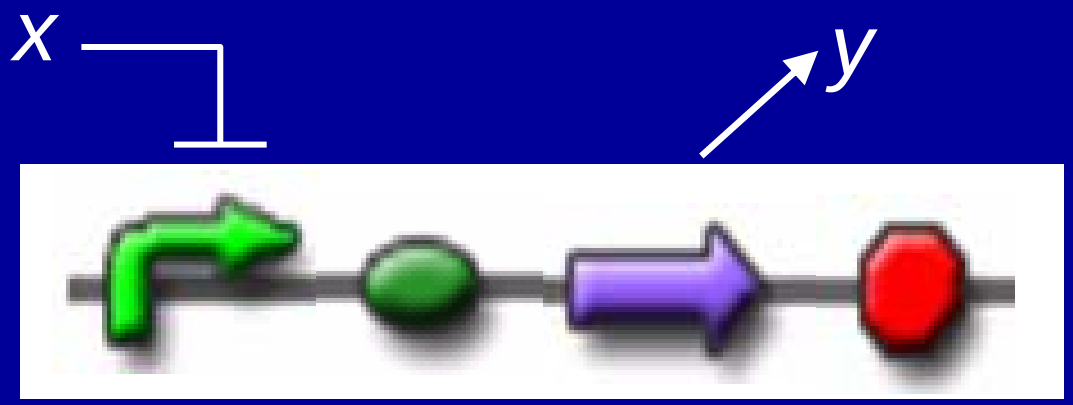
To engineer biology it needs to be broken down into parts

# The Engineering Approach



# Modelling

# An inverter described using BioBrick icons




Promoter Gene

$$\frac{dy}{dt} = \frac{\beta x^n}{K^n + x^n} - \gamma y$$

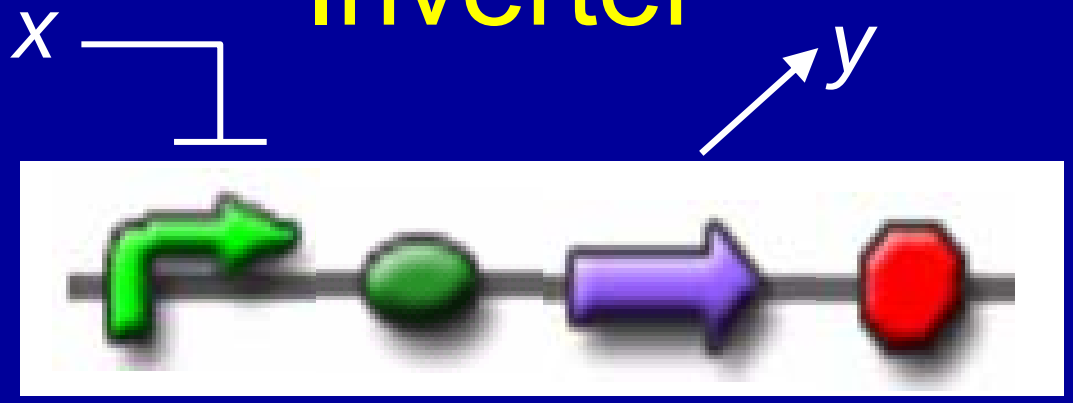
$\gamma$ Protein degradation rate

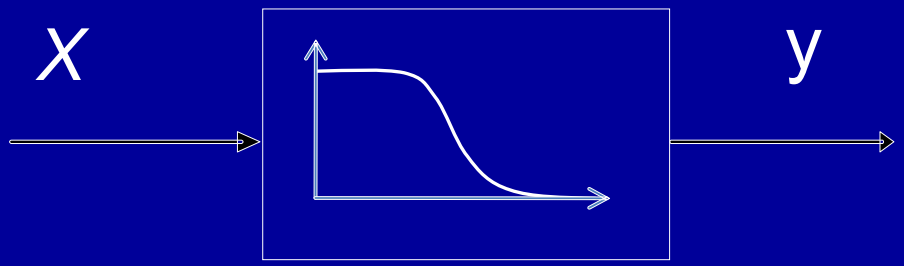
$x$ Input repressor protein

$n$ Hill constant

$\beta$ Protein synthesis rate

# Inverter

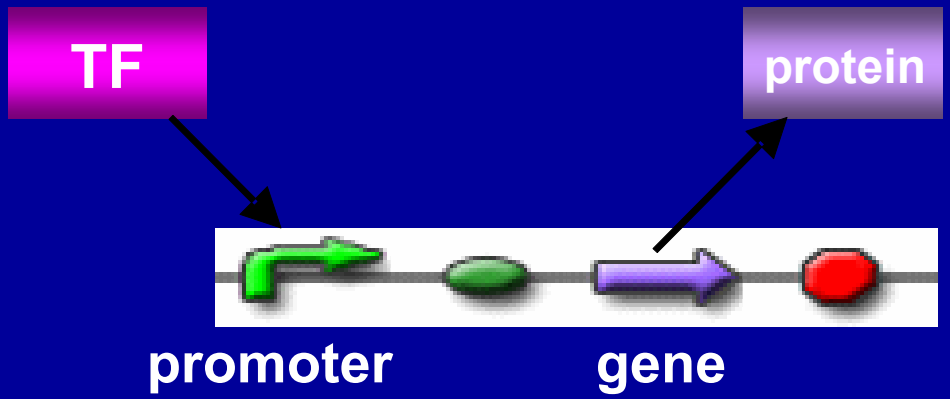



| X (Input Repressor) | Y (Output Protein) |
|---|---|
| 1 | 0 |
| 0 | 1 |

1: High Concentration
0: Low Concentration

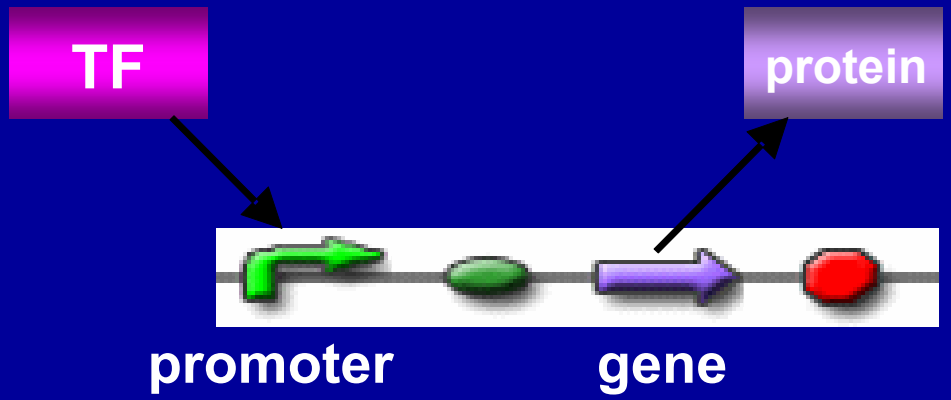
# A typical transcriptional regulatory device




$$\frac{d[mRNA]}{dt} = \frac{k_{tr} \cdot \left(\frac{W^n}{K^n}\right)^{\mu}}{1 + \left(\frac{W^n}{K^n}\right)} - d_m.[mRNA]$$

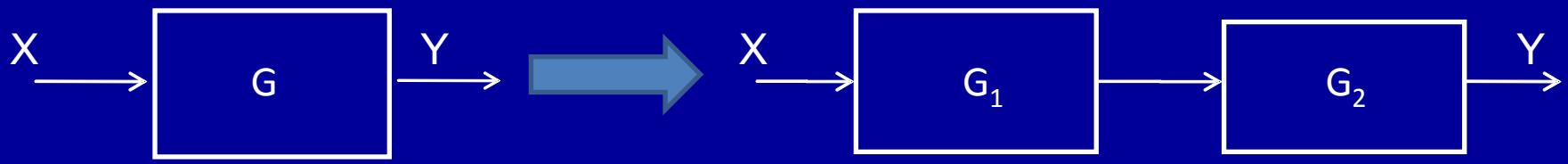
Currently ODEs are mainly used for modelling in Synthetic Biology

This becomes cumbersome as the complexity of the systems increases




What is required is the application of Systems Theory

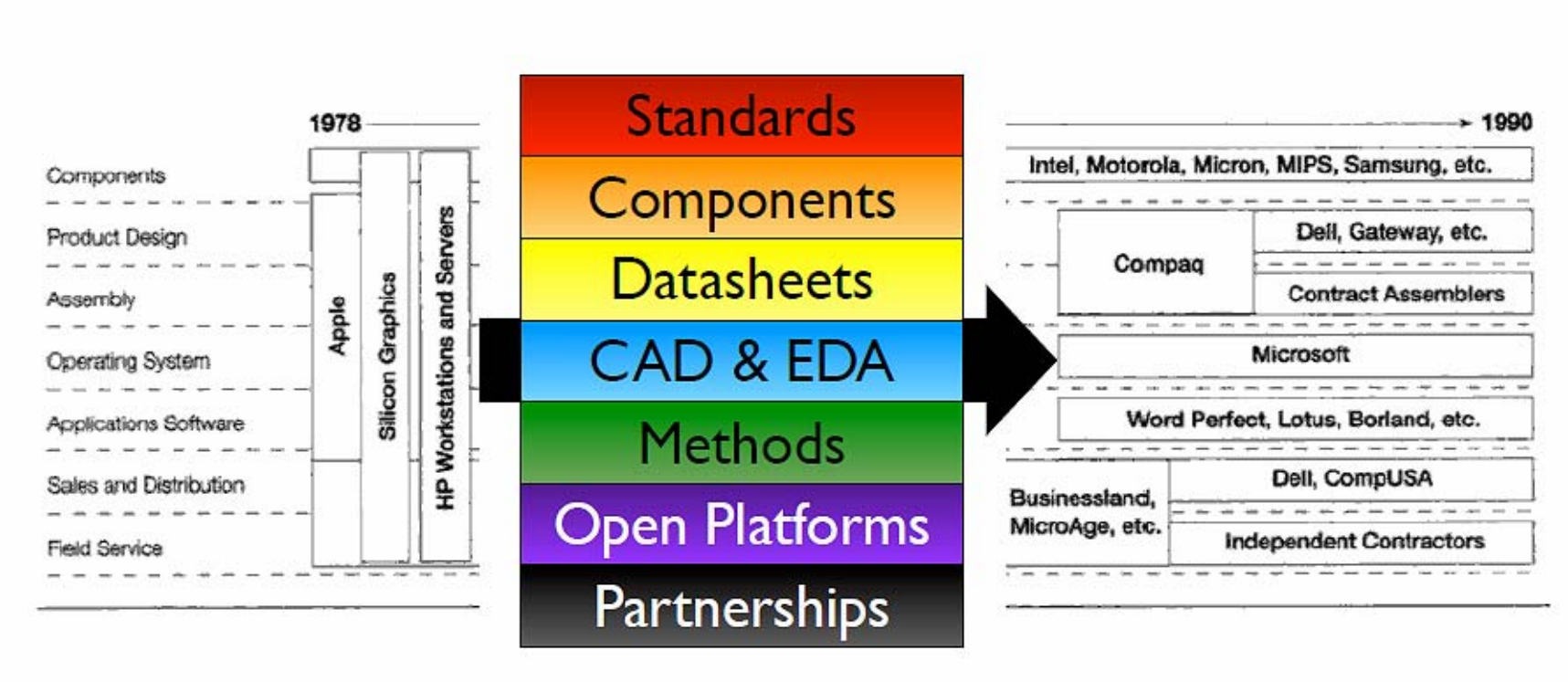
Modularisation




and, the application of Transform Methods

# The Evolution of Industrial Approaches

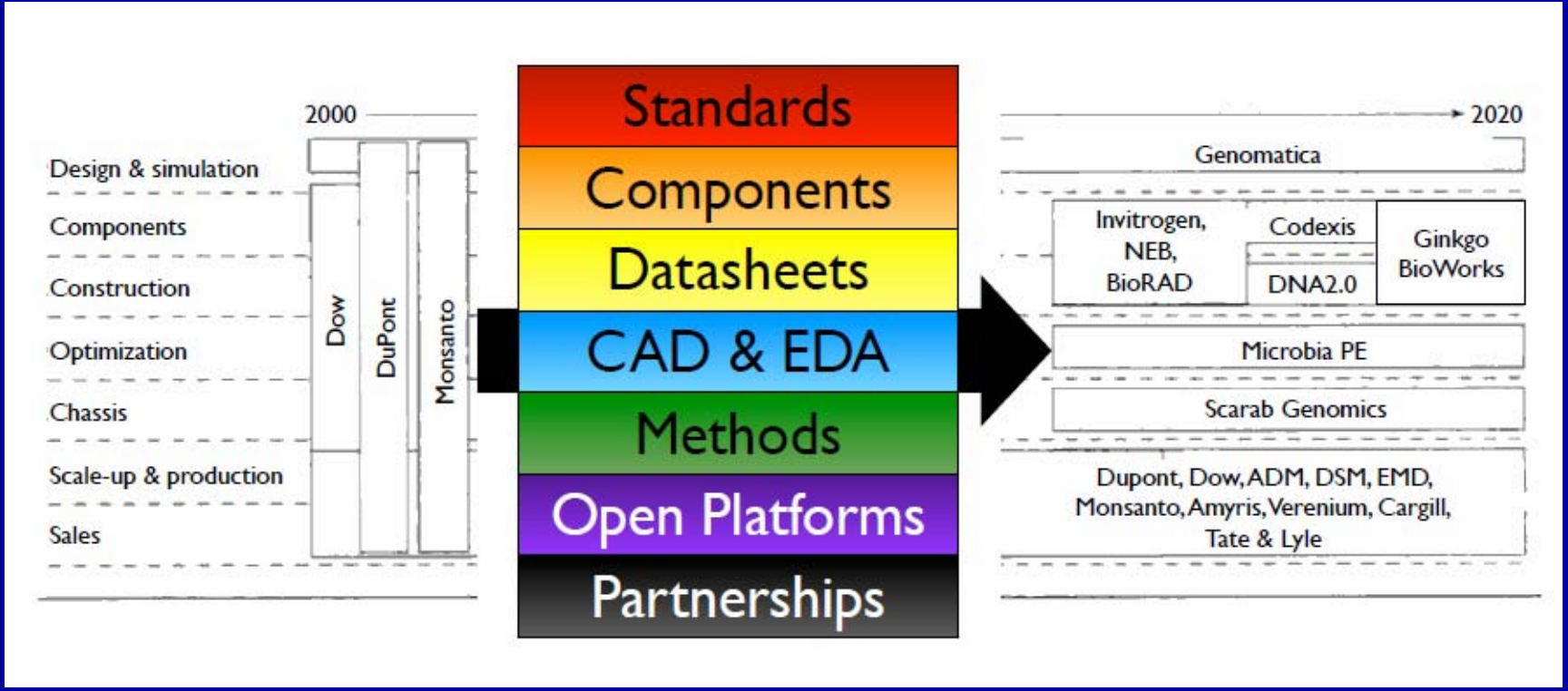
# Computing - circa 1980




New foundational tools catalysed revolutionary transitions in computer technology, creating new industries and huge opportunities

The Innovator's Solution - CM Christensen and M E Raynor – HBSP - 2003

# Biotech is Next




Poised for similar revolutionary reorientation from few successful vertical organisations to many partnered and enabling industries

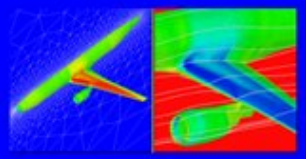
**Specification**

Part and Device Specification

**Design**

Part and Device Characterisation, and Design

**Modelling**



Implementation, Testing and Validation

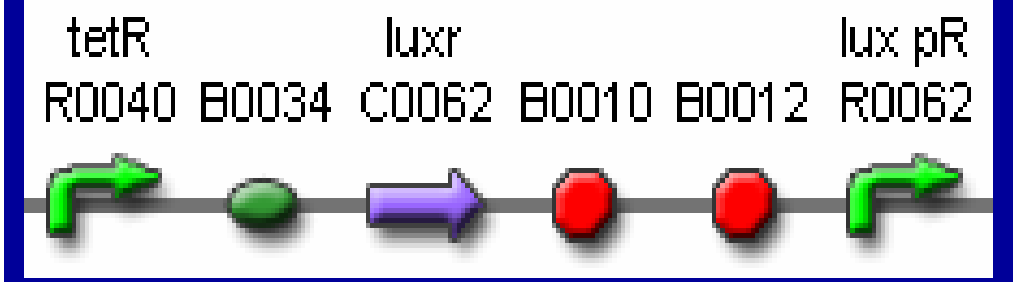
Small Scale Assembly of Parts and Devices in House

Large Scale Assembly of Parts and Devices within Gene Synthesis Companies

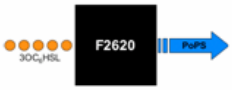
Applications Companies

- Healthcare
- Pharma
- Biofuels
- Agroscience

# Biobrick BBa_F2620




## BBa_F2620




3OC$_6$HSL → PoPS Receiver

http://parts.mit.edu/registry/index.php/Part:BBa_F2620

Authors:
Barry Canton [bcanton@mit.edu]
Anna Labno [labnoa@mit.edu]

Last Update: 5 October 2006

**Description**

A transcription factor (LuxR, BBa_C0062) that is active in the presence of cell-cell signaling molecule 3OC$_6$HSL is controlled by a TetR-regulated operator (BBa_R0040). Device input is 3OC$_6$HSL. Device output is PoPS from a LuxR-regulated operator. If used in a cell containing TetR then a second input signal such as aTc can be used to produce a Boolean AND function.

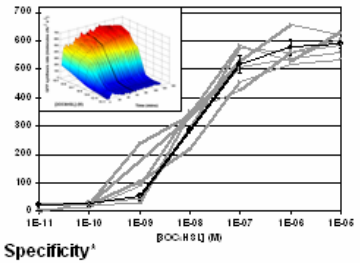
**Characteristics**

*Input Swing:* **0.1 to 1000** nM 3OC$_6$HSL, exogenous
*Output Swing:* **21±3 to 590±9** GFP molecules cfu$^{-1}$ s$^{-1}$
*Switch Point:* **10 nM** 3OC$_6$HSL, exogenous
*LH Response:* **9.7 min** ($t_{50\%}$), **17 min** ($t_{90\%}$)

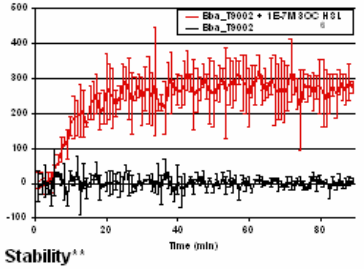
**Key Components**

*BBa_R0040:* TetR-regulated operator
*BBa_C0062:* luxR ORF
*BBa_R0062:* LuxR-regulated operator

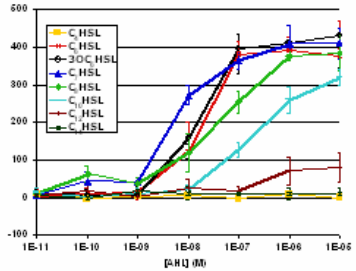
**Transfer Function***



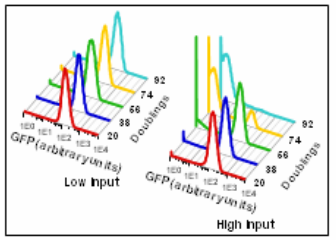
**Response Time***




**Specificity***




**Stability****




**Demand** (low/high input)

*Translational:* **336/9449** ribosomes cfu$^{-1}$
**5040/141600** charged tRNA cfu$^{-1}$ s$^{-1}$

**Stability** (low/high input)

*Genetic:* **>92/74** replication events*
*Performance:* **>92/74** replication events*

**Compatibility**

*Chassis:* Compatible with *MC4100*, *MG1655*, and *DH5α*
*Plasmids:* Compatible with *pSB3K3* and *pSB1A2*
*Devices:* Compatible with *E0240*, *E0430* and *E0434*
Crosstalk with systems containing *TetR (C0040)*
*Signaling:* Crosstalk with input molecules similar to *3OC$_6$HSL*

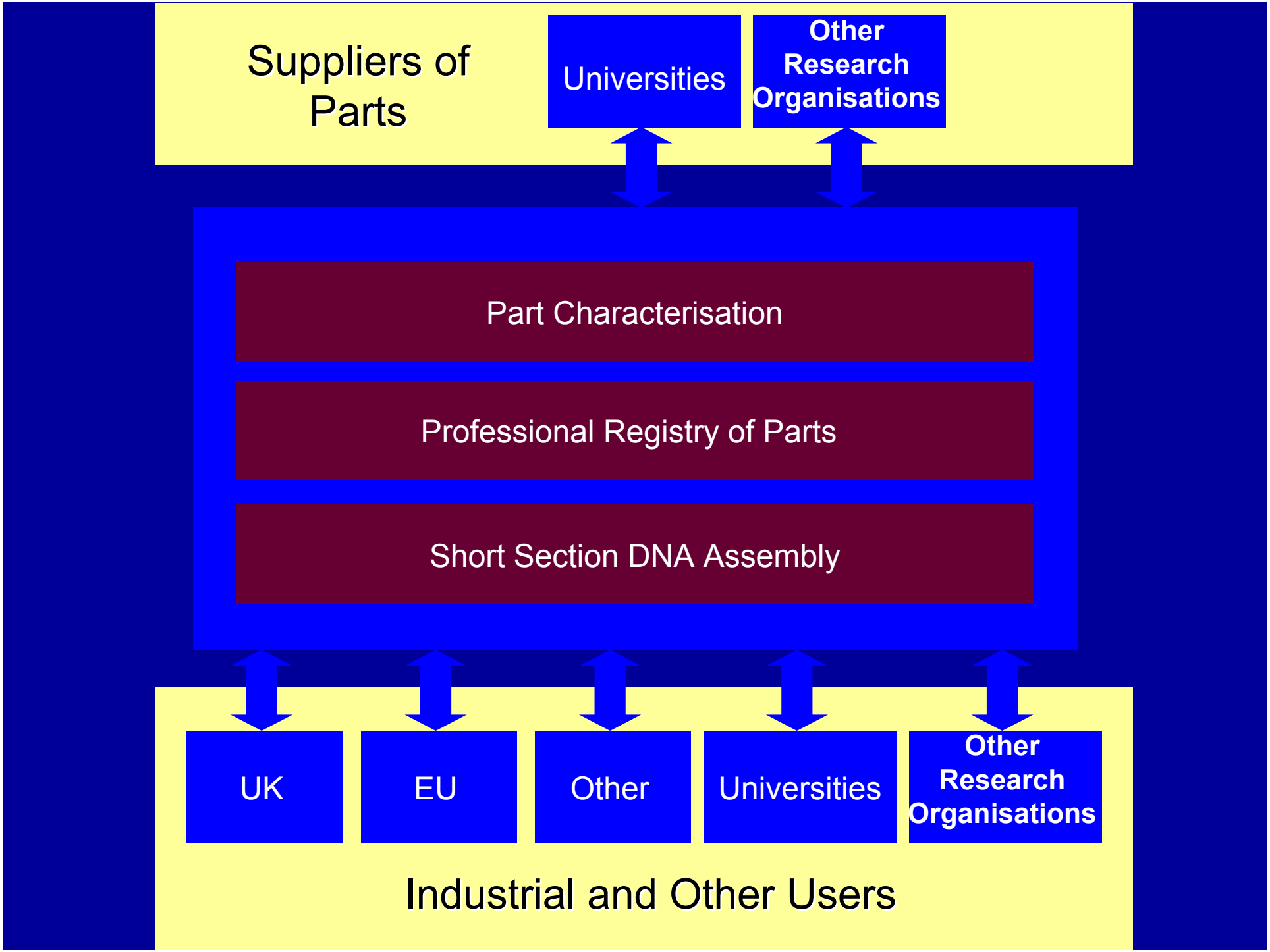
**Conditions (abridged)**

*Output:* Indirect via *BBa_E0240*
*Vector:* pSB3K3
*Chassis:* MG1655
*Culture:* Supplemented M9, 37°C
**Equipment:* PE Victor3 plate reader
***Equipment:* BD FACScan cytometer

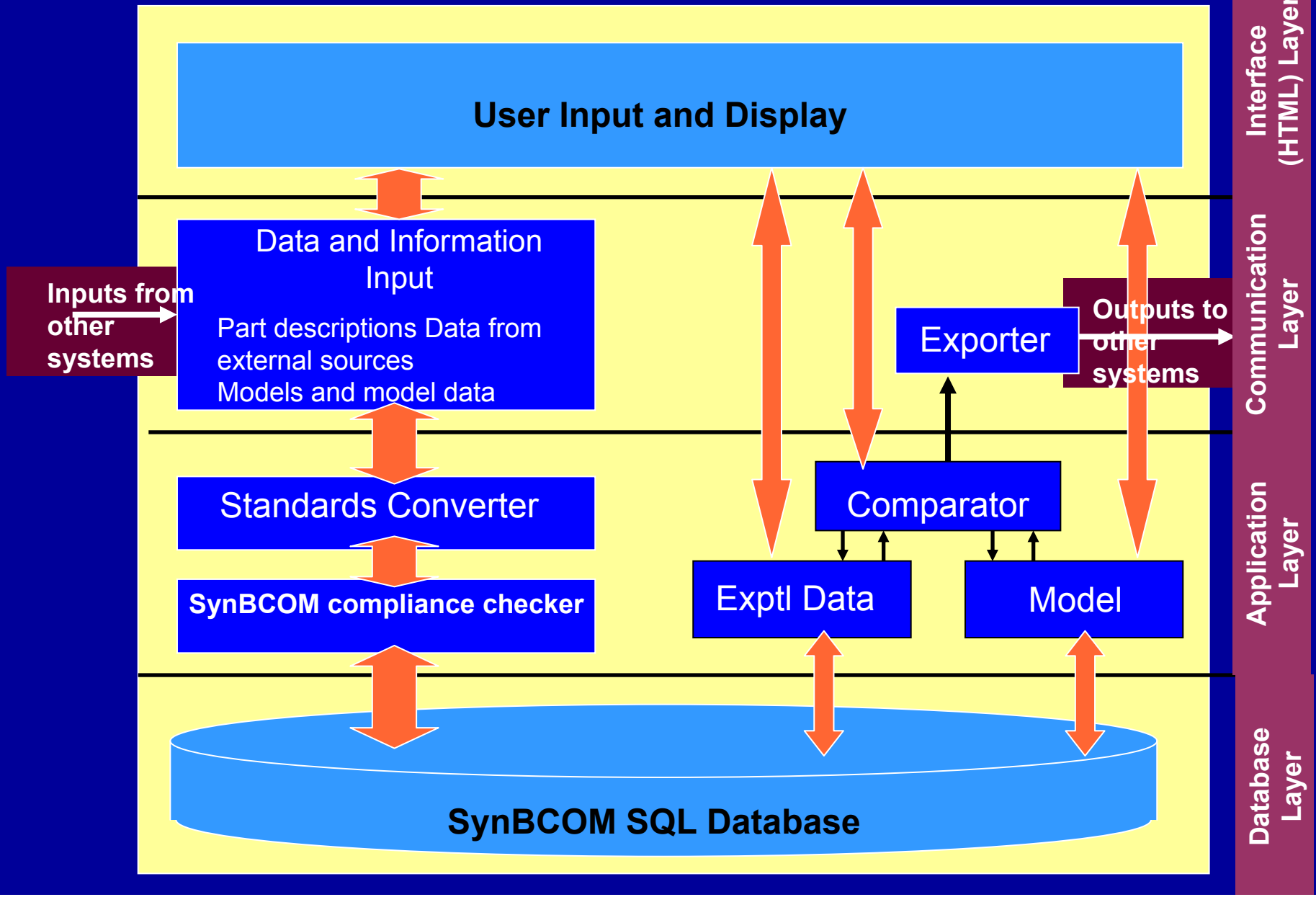
Registry of Standard Biological Parts
*making life better, one part at a time*

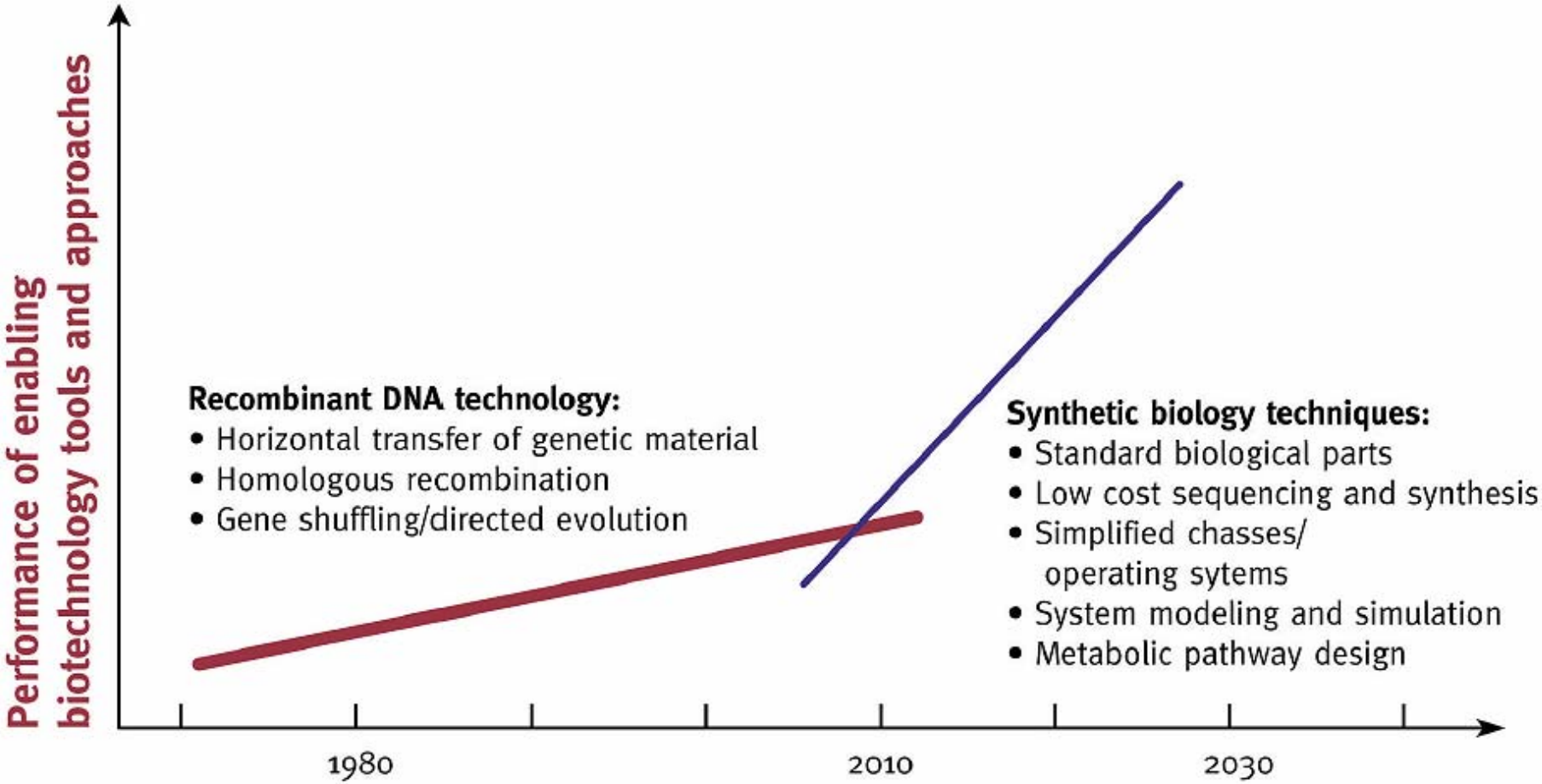
License: Public

Signaling Devices


Suppliers of Parts
Universities
Other Research Organisations
Part Characterisation
Professional Registry of Parts
Short Section DNA Assembly
UK
EU
Other
Universities
Other Research Organisations
Industrial and Other Users

# A SynB Information System

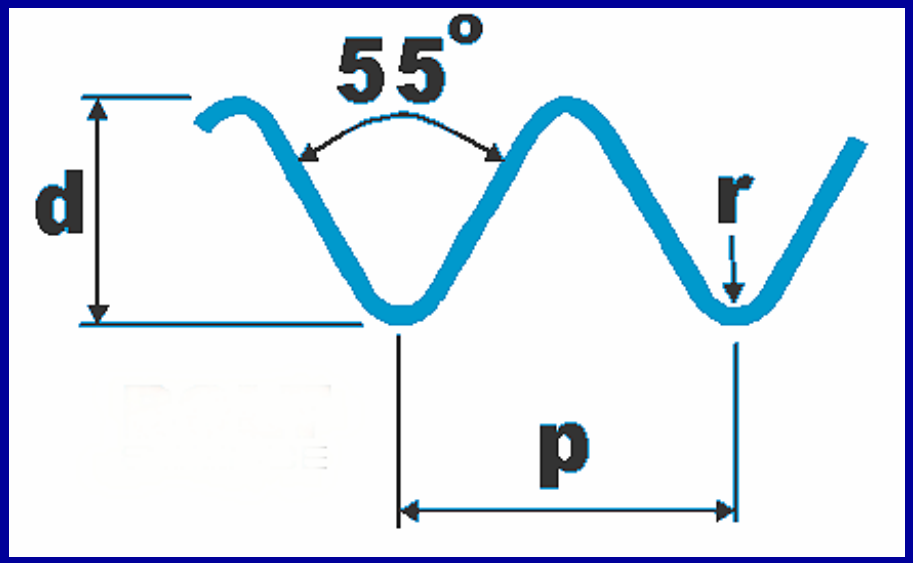




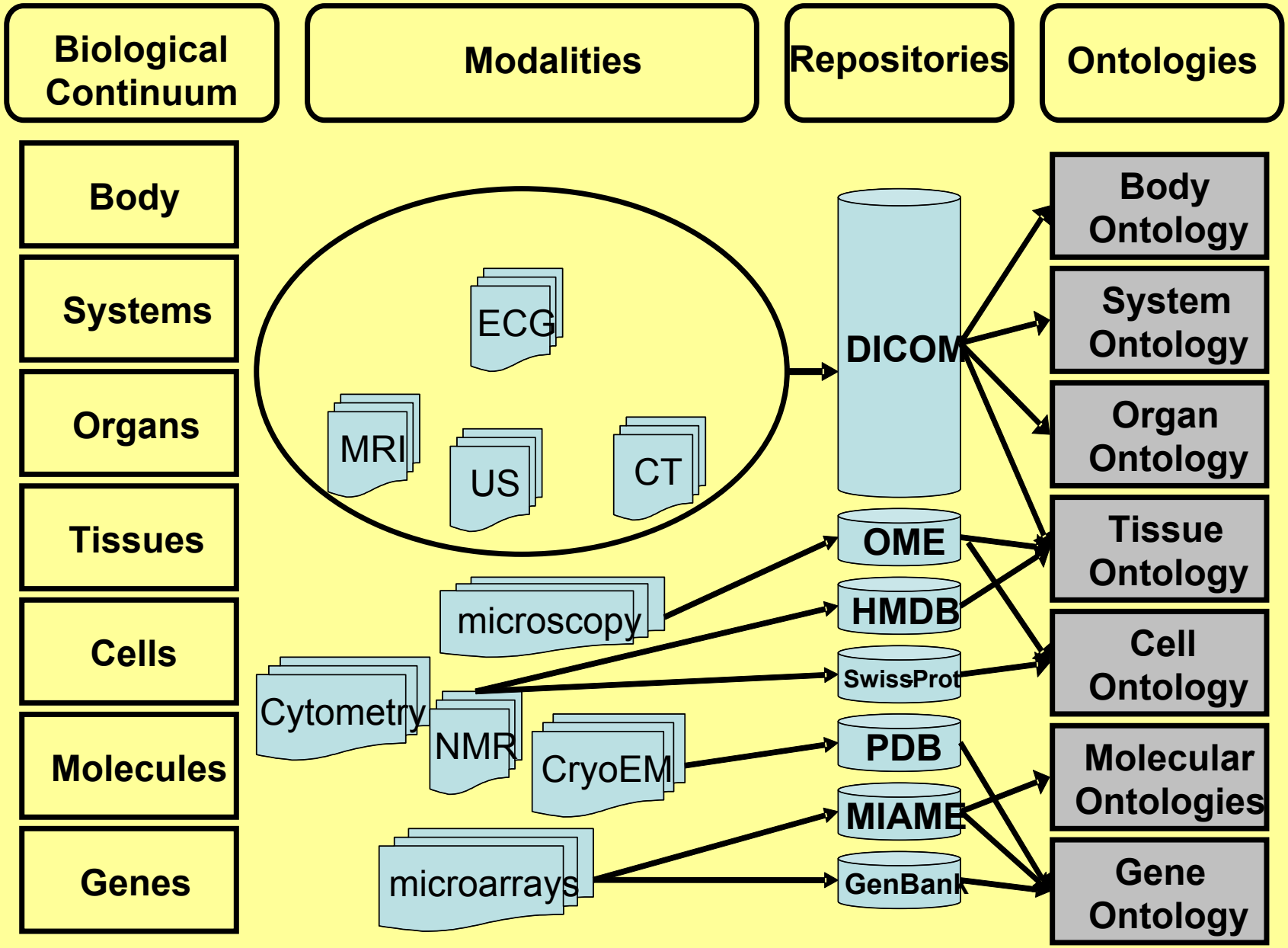

Genome Synthesis and Design Futures - Special Bio-era Report – US DoE 2007

# Standards

# The Whitworth Thread




The first standard thread – Sir Joseph Whitworth 1841


Biological Continuum
Modalities
Repositories
Ontologies
Body
Systems
Organs
Tissues
Cells
Molecules
Genes
ECG
MRI
US
CT
microscopy
Cytometry
NMR
CryoEM
microarrays
DICOM
OME
HMDB
SwissProt
PDB
MIAME
GenBank
Body Ontology
System Ontology
Organ Ontology
Tissue Ontology
Cell Ontology
Molecular Ontologies
Gene Ontology


NEMA, Suite 1752
1300 North 17th Street
Rosslyn, VA 22209
Ph: (703) 841-3285
http://dicom.nema.org

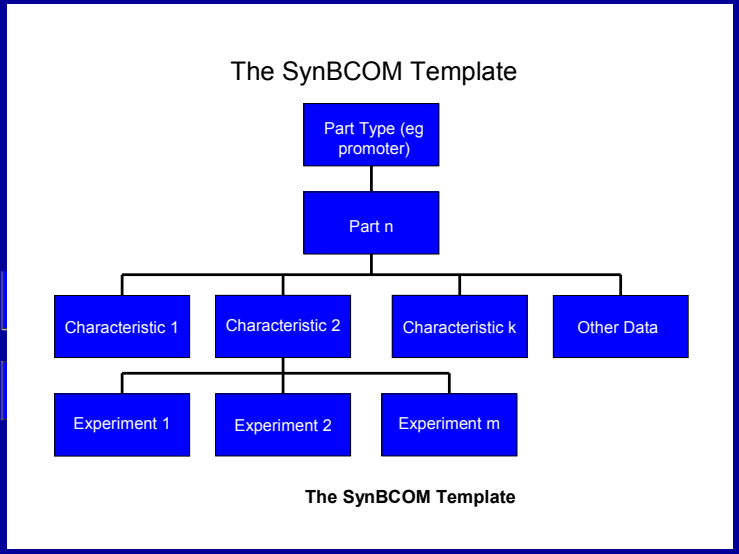
http://medical.nema.org/

Based on the DICOM standard for medical images
http://medical.nema.org/

Machine readable to allow programmes to collate, search and update the information contained where appropriate

Parts will be ontologically organised to aid design

Parts will be defined by their characteristics, which are determined by experiments and data which will be associated with the part



# Synthetic Biology's Engineering Principles

Characterisation, Standardisation and Automation

Characterisation:

- Of parts and their parameters and characteristics
- To produce models and improve understanding
- To aid design and prediction

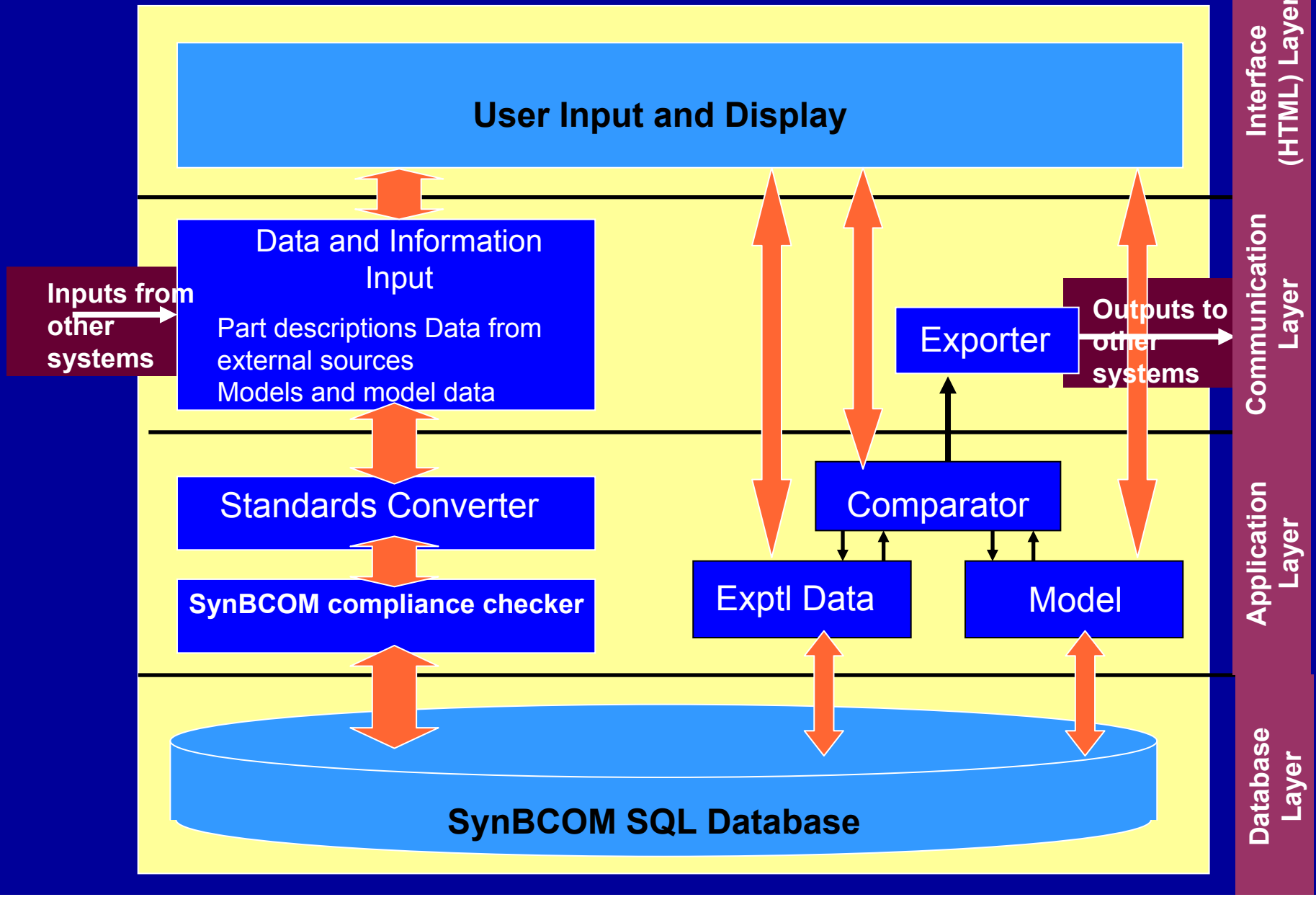
Standardisation

- Of many part types to ensure correct part inter-connectivity, function and insulation
- Of part ontology and documentation

Automation

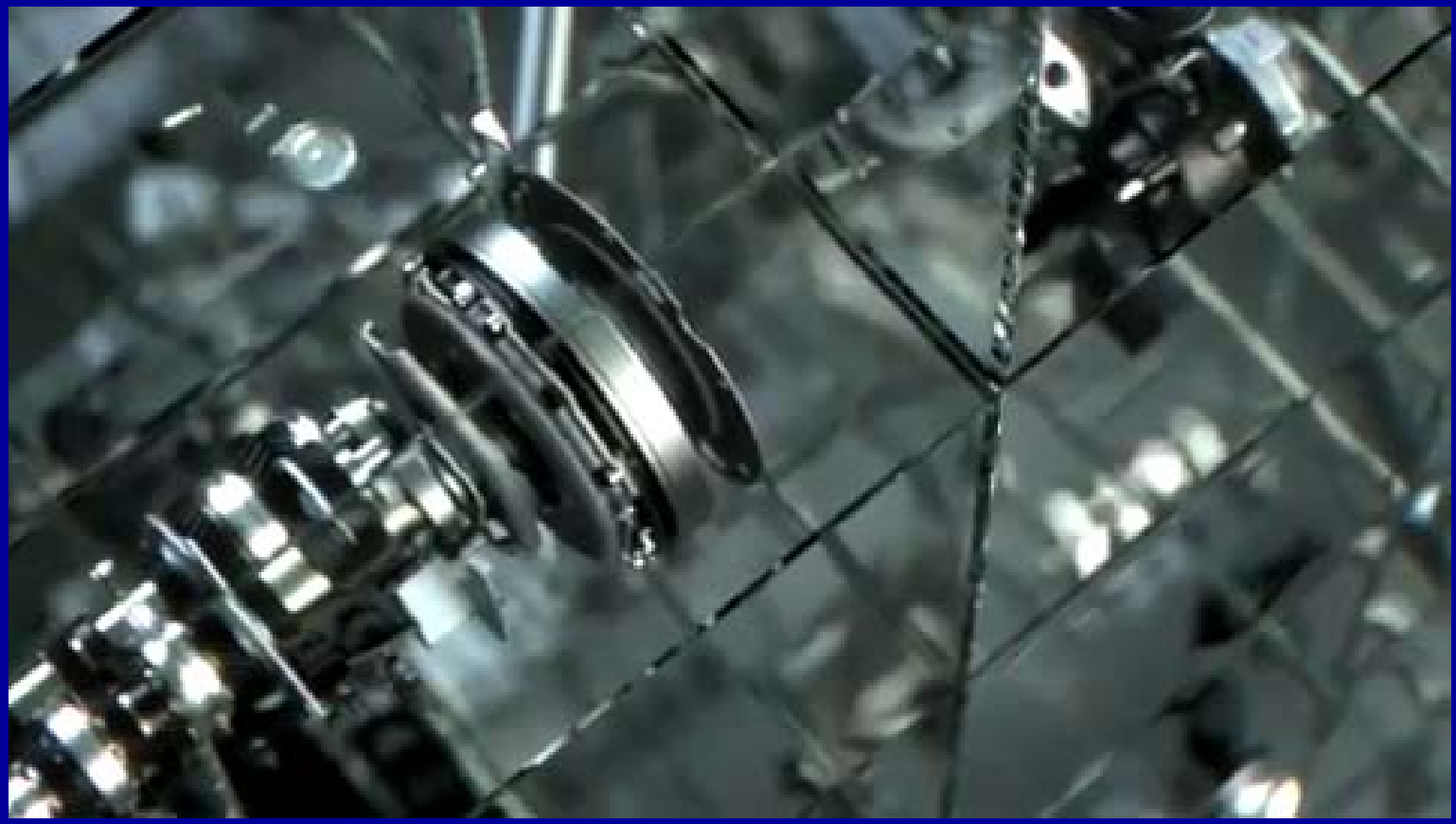
- Increase throughput
- Reduce researcher 'waiting' time
- Use of tools to speed up both design and lab processes

# A SynB Information System



# Developing a Registry of standard, composable models

# Combining parts



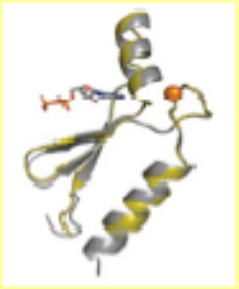
To predict the behaviour of complex systems built from many parts, we need to have:

1. *mechanisms to compose* part models into a system model
2. *predictive, composable models* for the parts

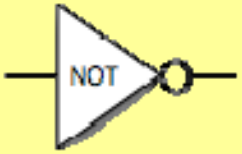
# Complex Systems & Abstractions

DNA → Parts → Devices → Systems → Hosts → Cell Populations

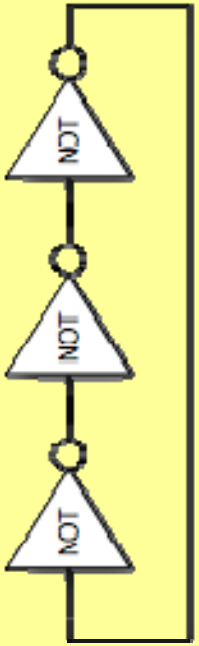
TAATACGACT



- PROMOTER
- RBS
- CODING SEQ.
- TERMINATOR
- ...




- INVERTER
- REPORTERS
- SENDERS & RECEIVERS
- ...




- E. COLI
- B. SUBTILIS
- YEAST
- MAMMALIAN CELLS
- ...

APPLICATIONS: BIOFUELS, BIOSENSORS, BIOMATERIALS, ...

To predict the behaviour of complex systems built from many parts, we need to have: predictive, composable models for the parts mechanisms to compose part models into a system model

# Current tools

- There are already many *systems biology model repositories* (e.g., Biomodels, CellML model repository, Open Wetware repository, Java web simulation online, ModelDB, etc.) and *model analysis and design tools* available.

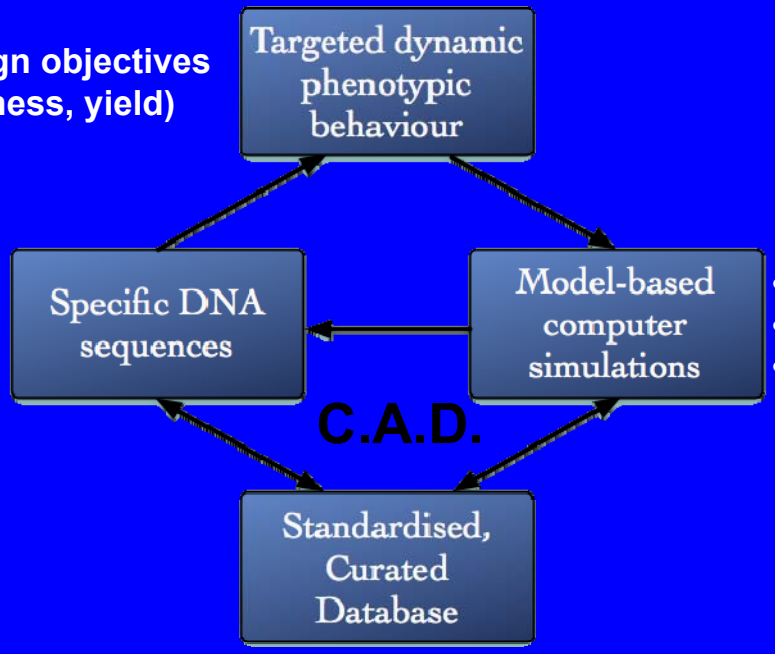
- However, these repositories and tools lack some of the important features of a *proper SynB C.A.D. framework*

- They hardly support the modular building process used to create complex systems from the interconnection of parts and forming an integral part of the engineering cycle

- They do not provide a unified C.A.D. environment with access to composable and reusable mathematical models

# What is needed ?

**Definition of the design objectives (behaviour, robustness, yield)**




- **Biological realisation & testing**
- **Experimental results**

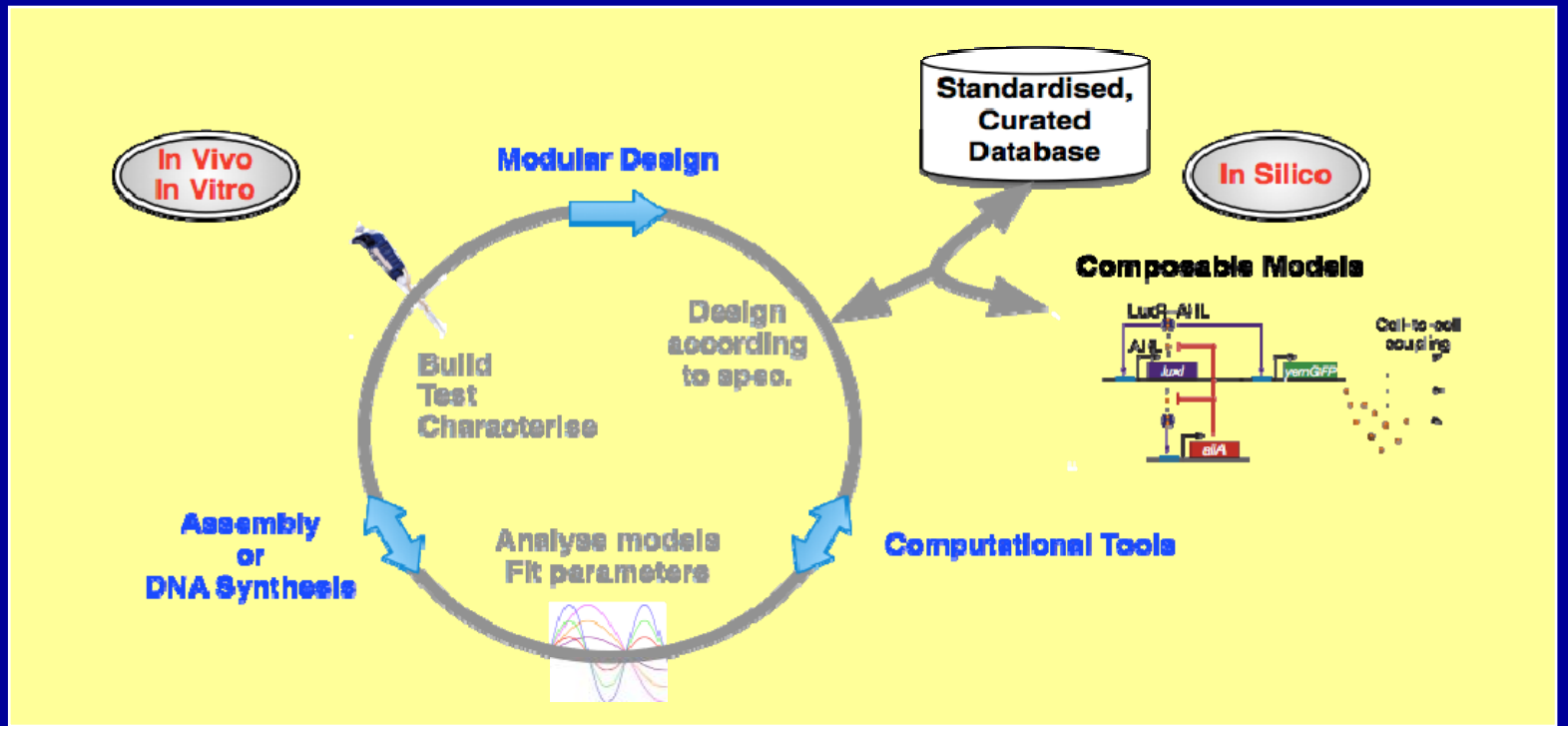
- **Possible design alternatives**
- **Param. estim. & modulation**
- **Robustness & sensitivity anal.**

- A *modular in silico C.A.D.* framework allowing:
- Easy design, simulation, and *composition* of *SynB models*
- Direct robustness and sensitivity analysis of models
- Seamless integration with a standardised & curated database:
  - search & annotation of part models based on design spec
  - search & modulation of model parameters
  - automated DNA sequence prediction & *de novo* synthesis

# CAD and Professional Model Registry

In parallel with increasing the number of available parts and characterising them professionally, a logical extension would be to build a *registry of standard, composable models* together with an appropriate *synthetic biology C.A.D.* environment

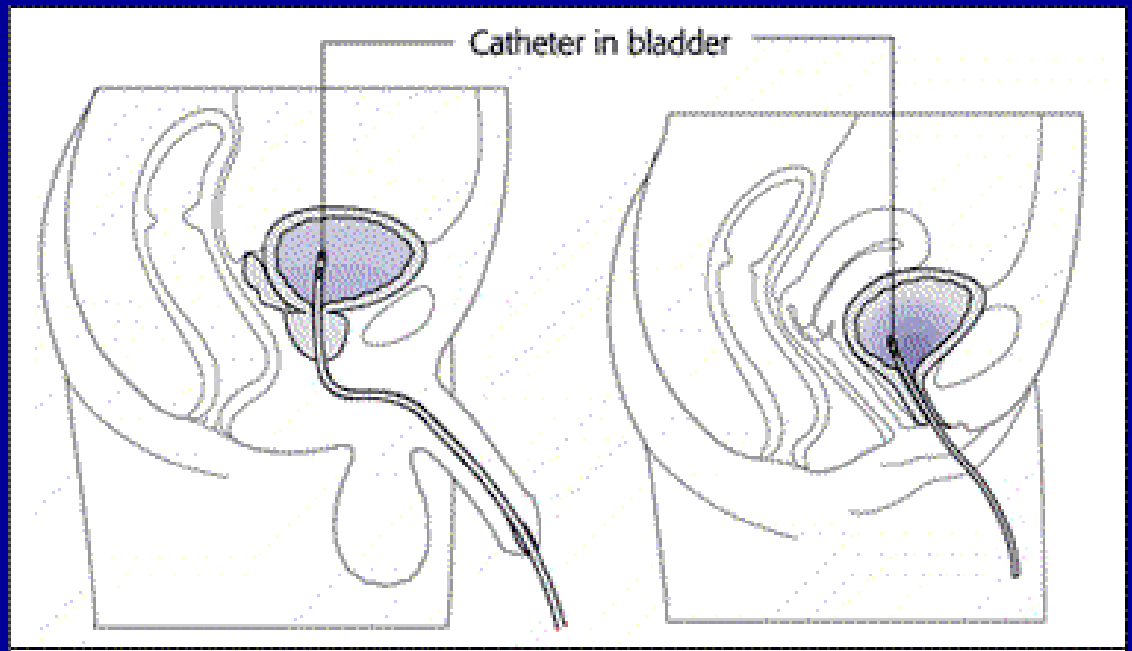
*Engineering design cycle*



# Example 1 – Urinary Tract Infection (UTI)

# The Problem

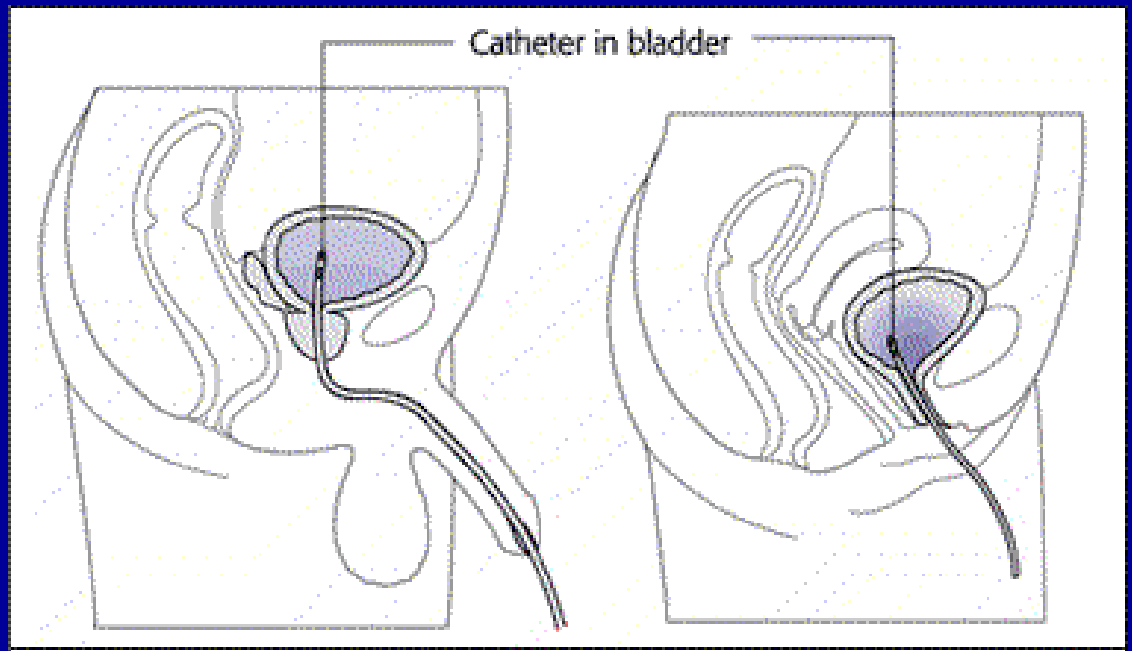
Infections take the form of a biofilm that creeps up the catheter into the urethra




Male and female lower urinary tract

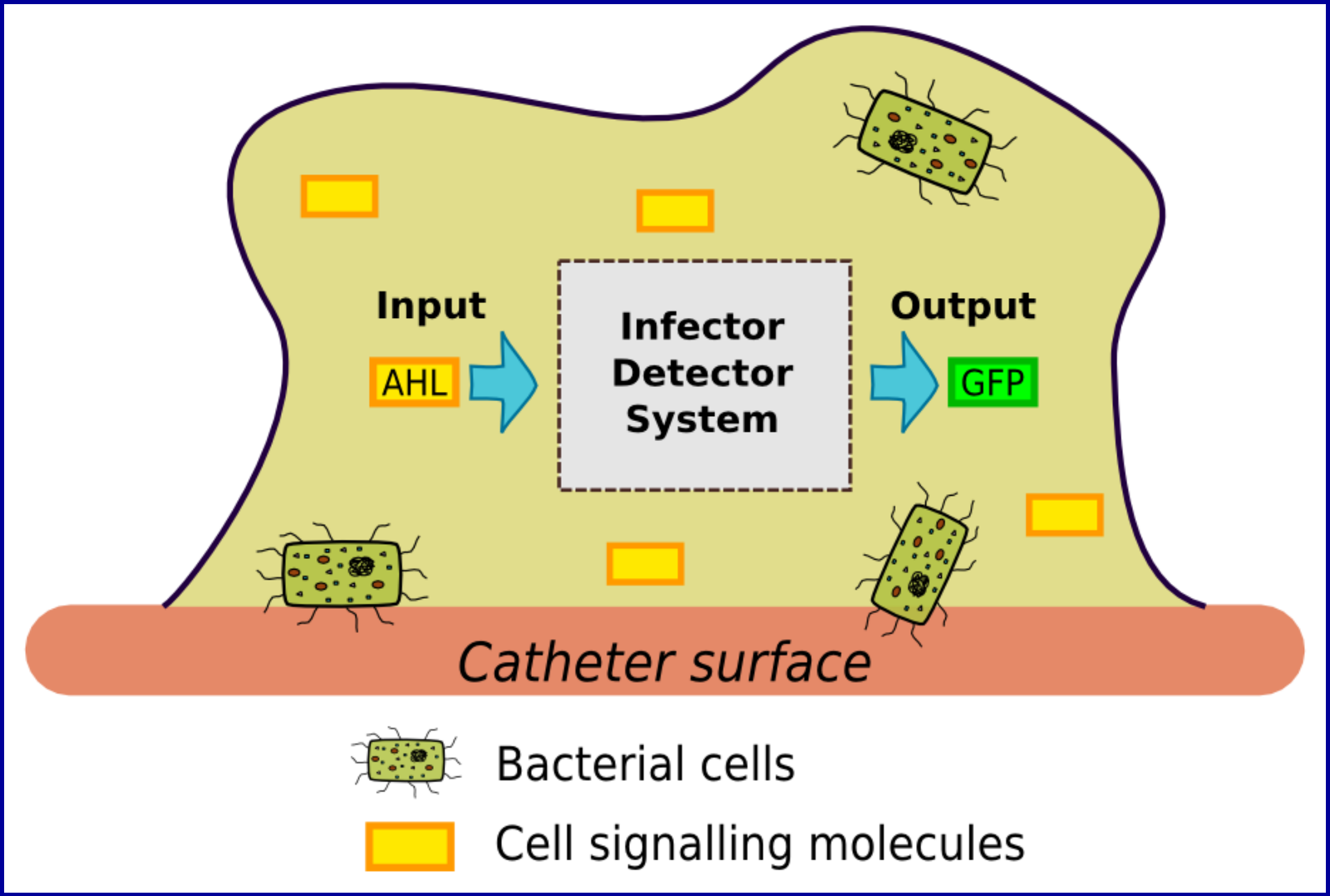
# Our Aim

To design a genetically engineered machine which detects the presence of biofilm infection on urinary catheters




Male and female lower urinary tract

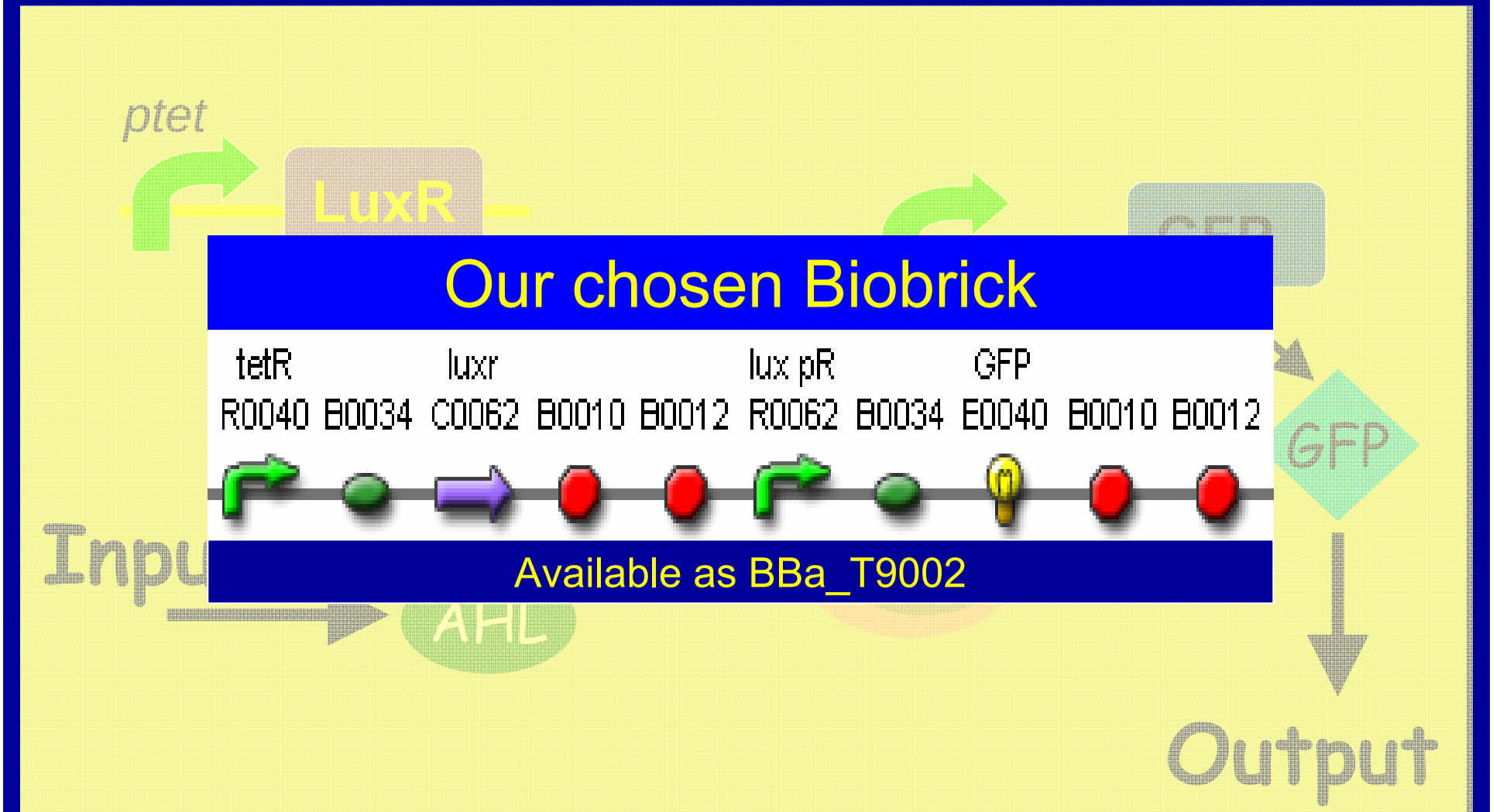
# Our Detection Strategy

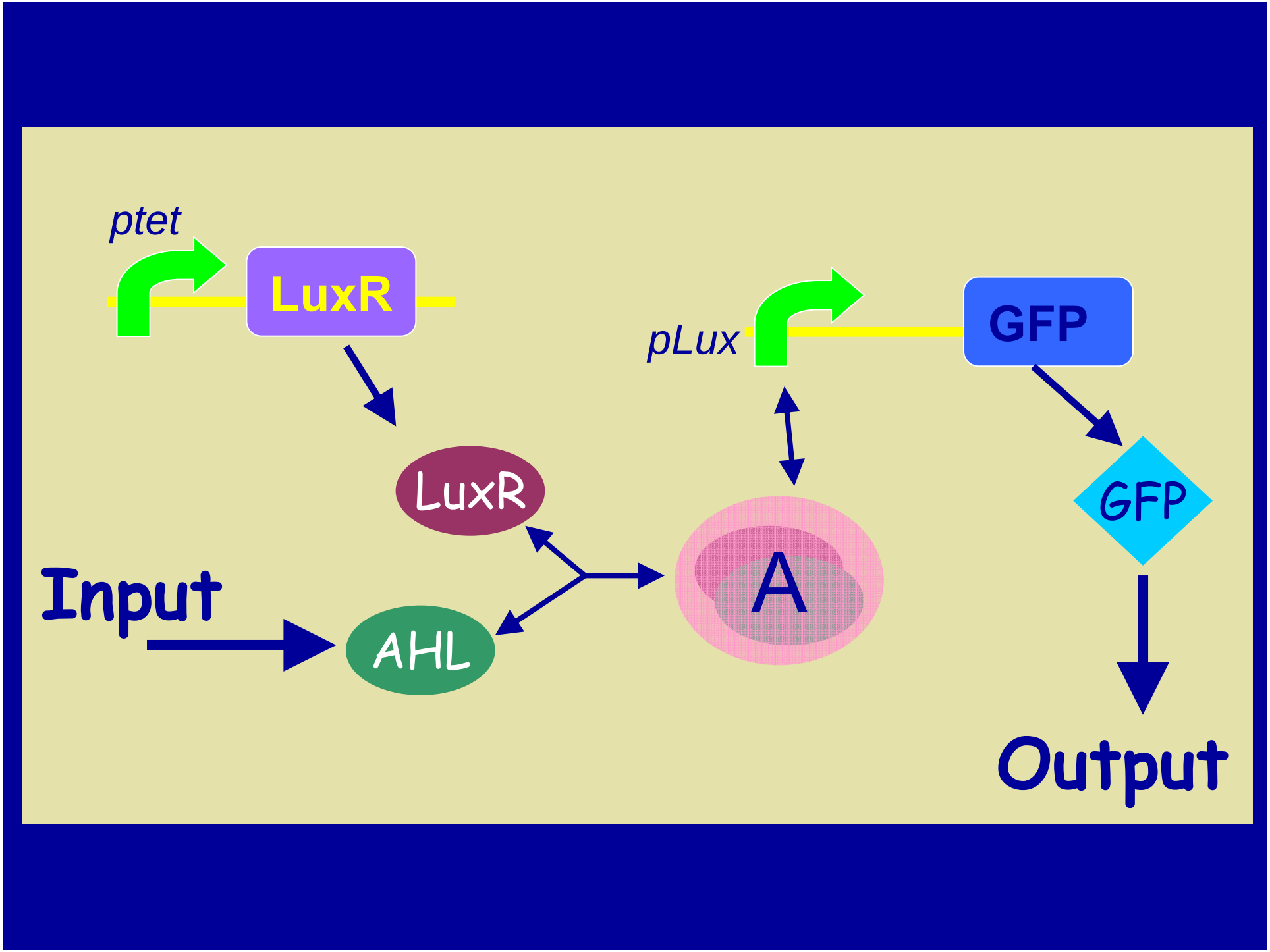


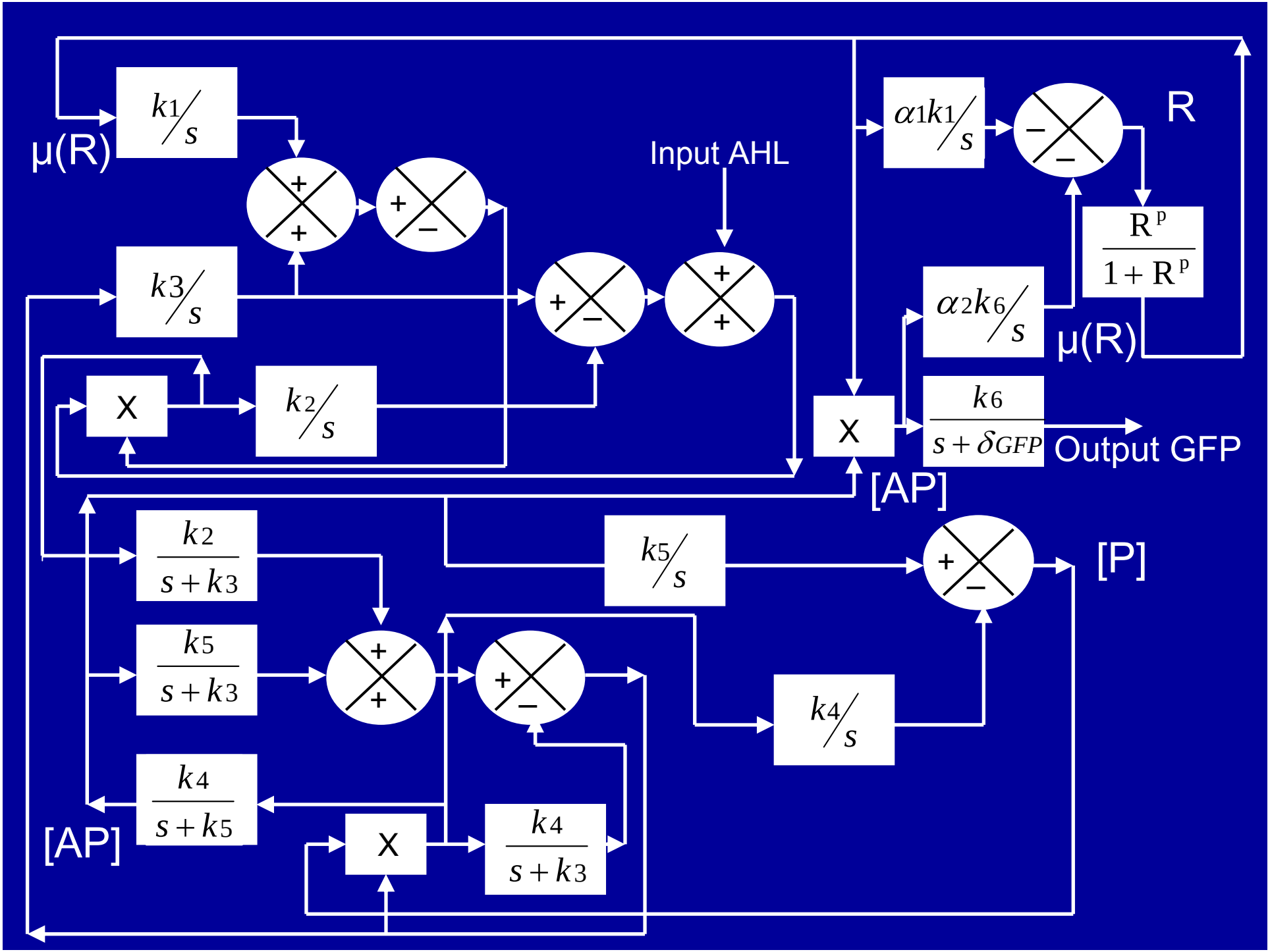
# Urinary Tract Infection Detector – a three stage device


| Detector | Amplifier | Indicator |
|---|---|---|

# The Biochemical Network – the basis of Infector Detector



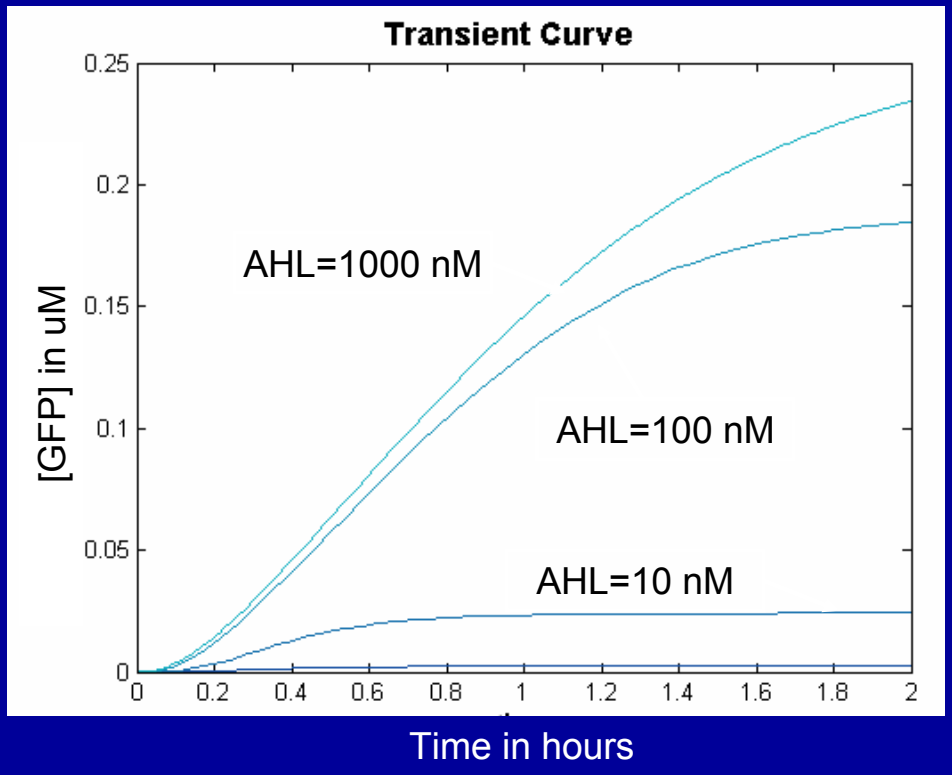

ptet
LuxR
pLux
GFP
LuxR
GFP
Input
A
AHL
Output


μ(R)
$k_1/s$
Input AHL
$\alpha_1 k_1/s$
R
$R^p/(1+R^p)$
$k_3/s$
$\alpha_2 k_6/s$
μ(R)
X
$k_2/s$
X
$k_6/(s+\delta_{GFP})$
Output GFP
[AP]
$k_2/(s+k_3)$
$k_5/s$
[P]
$k_5/(s+k_3)$
$k_4/s$
$k_4/(s+k_5)$
[AP]
X
$k_4/(s+k_3)$

# Typical Simulations

## General Behaviour:

- Slow uptake
- Saturation after few hours (Resources exhausted)
- The higher the input (AHL) , the higher the output ( GFP)

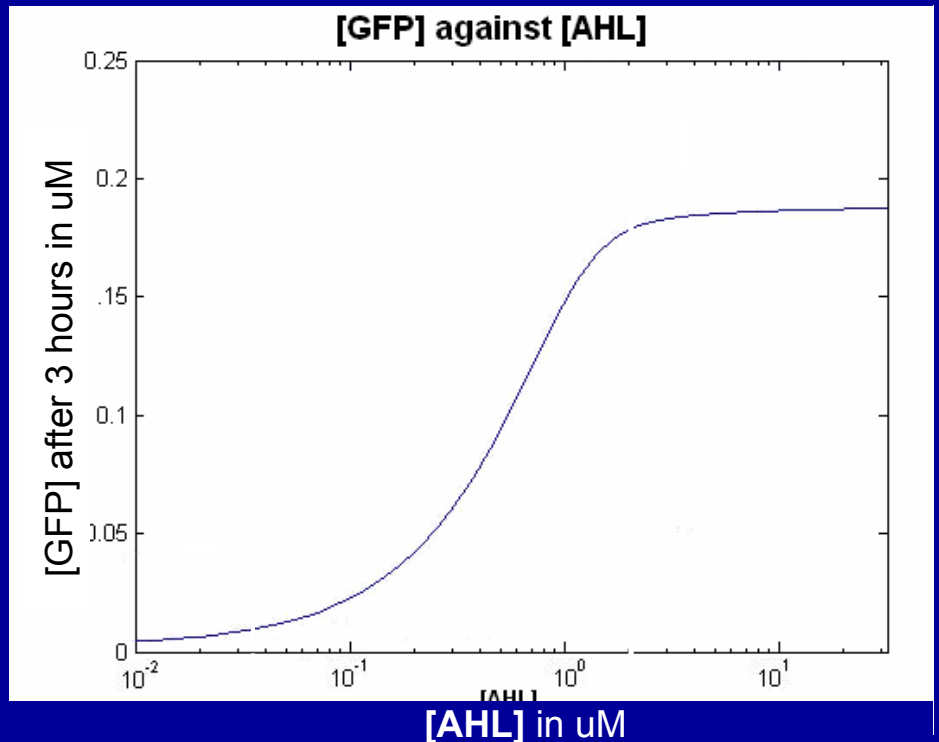


# Transfer Function

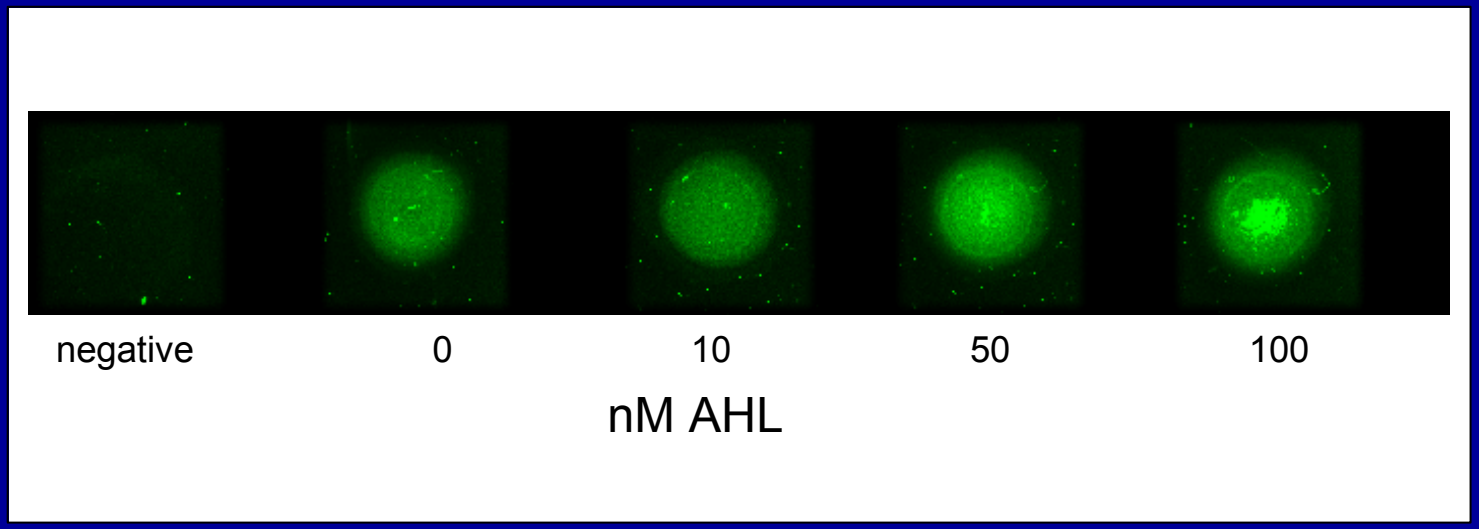
**AHL** → **Infector Detector** → **GFP**

## GFP vs AHL

- Similar to F2620 in vivo
- Below $T_1$ : No detection
- Above $T_2$: Saturation

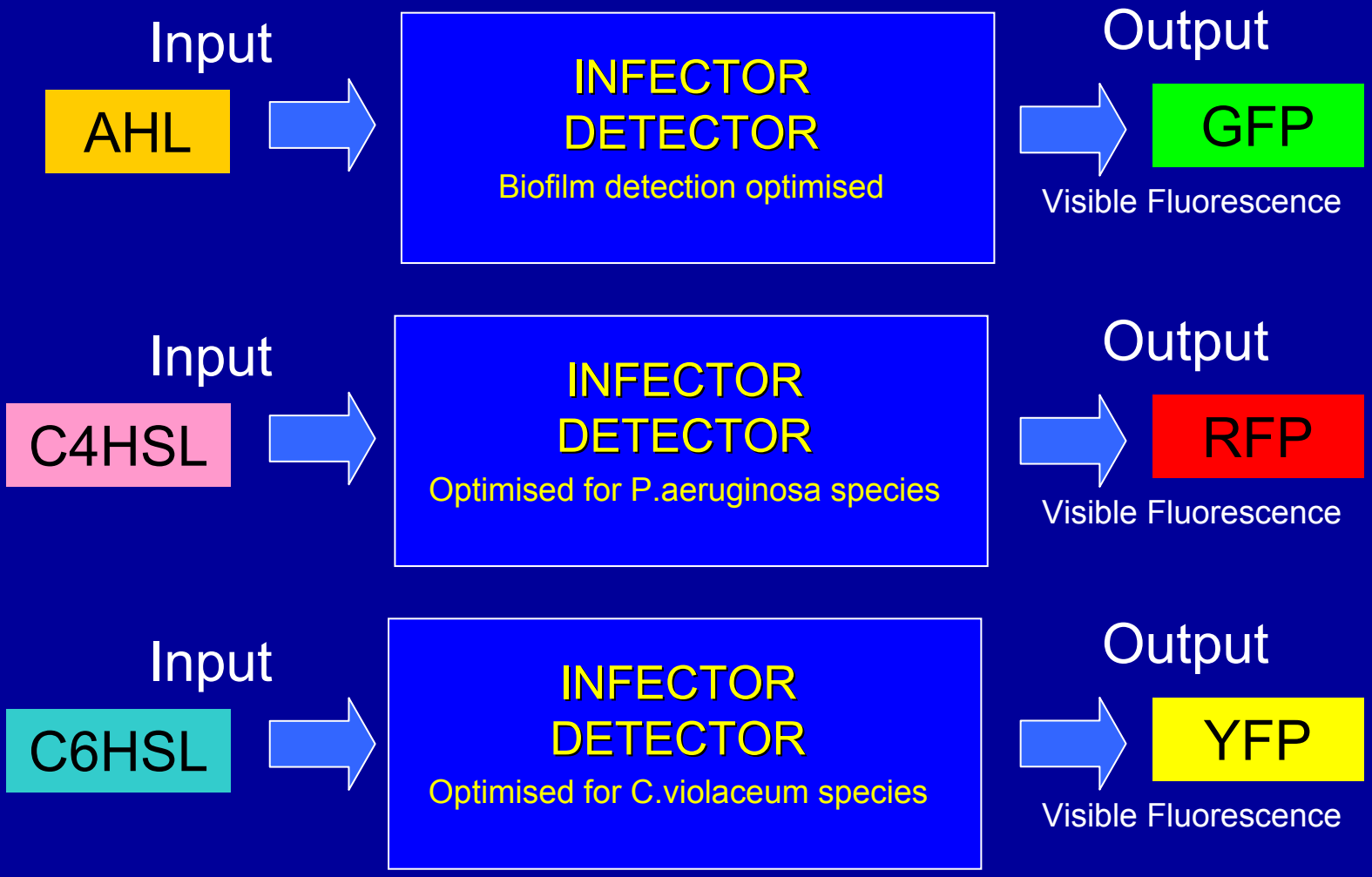


# Testing Infector Detector on Agarose




Agarose drops with Infector Detector detecting different concentrations of AHL

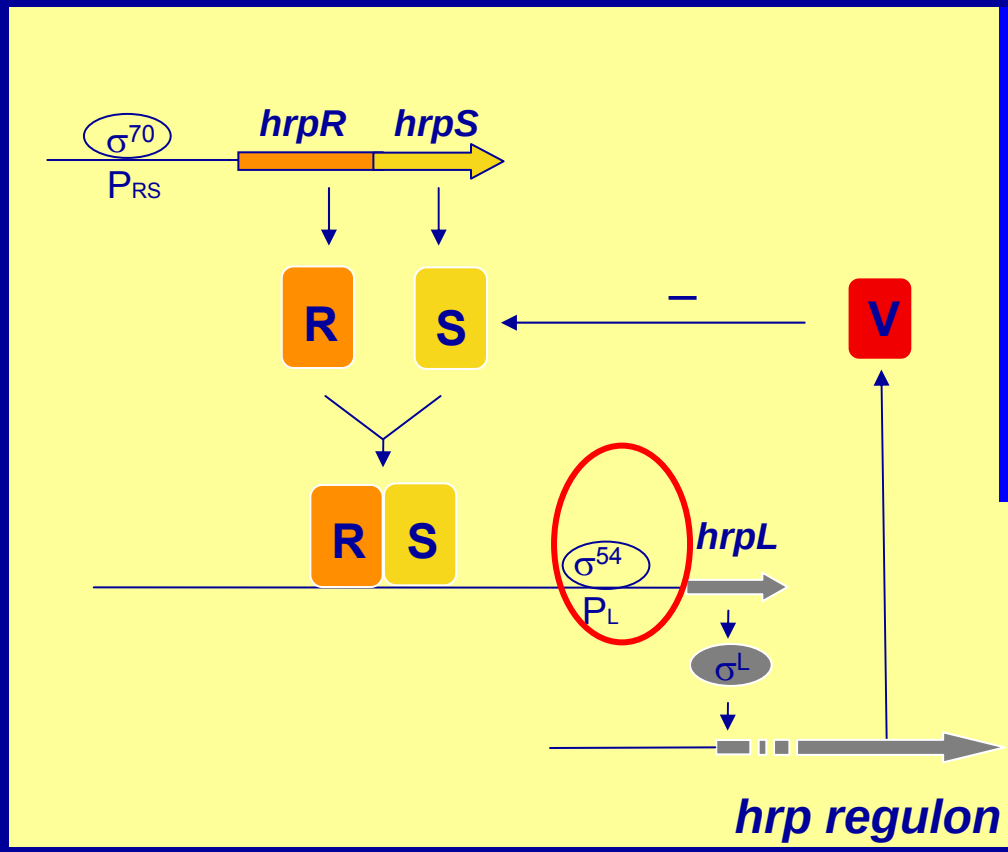
# Ongoing Work: Customisation



# Example 2 – Logic Gates

# *The hrp* gene regulation system – a great system for modular biologically-based logical devices

- *hrp* (hypersensitive response and pathogenicity)




## Advantages

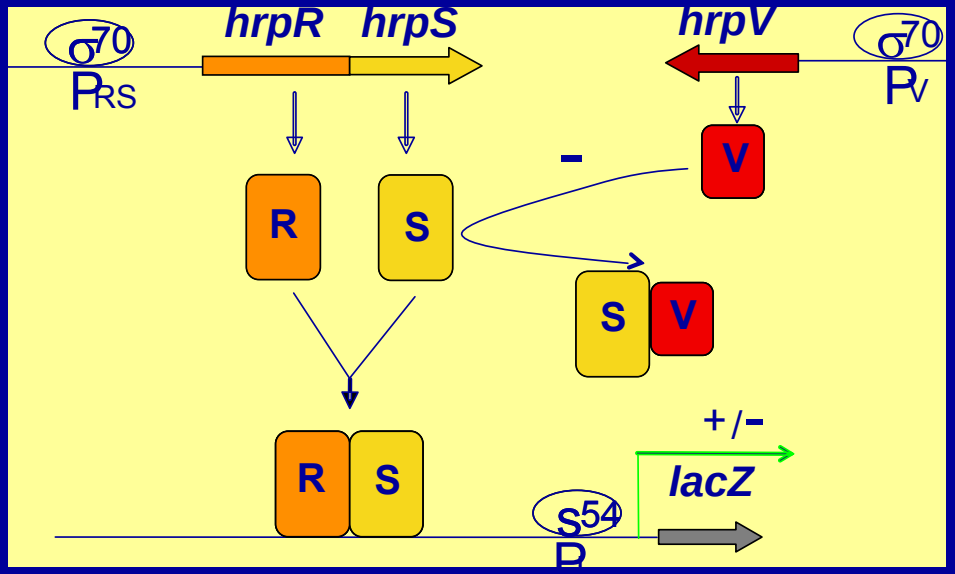
- sigma factor 54
- 2nd paradigm of gene activation
- multiple regulation factors
- protein-protein interactions
- high cooperatively

Type III Protein Export Complex

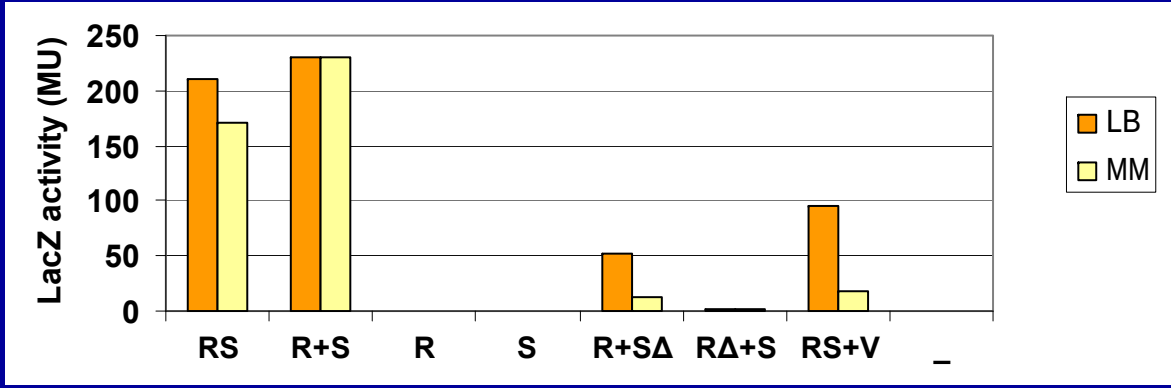
***Pseudomonas syringae hrp* regulatory system**

# Biological Experimental Results

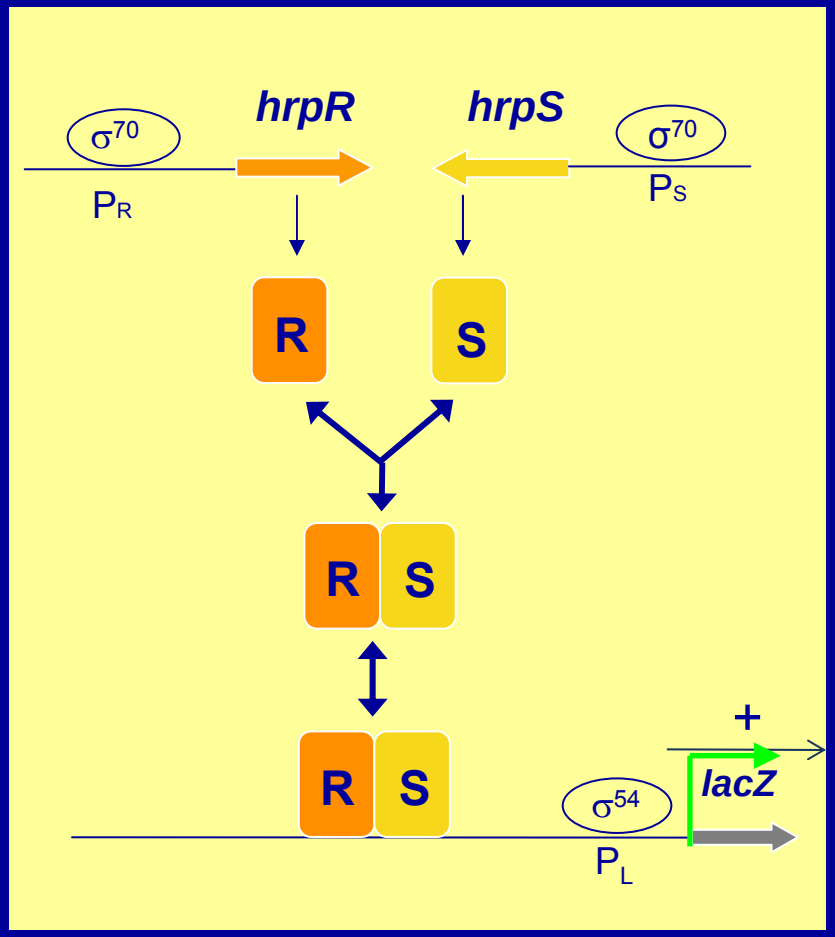
Identifying regulation mechanism for *hrpL* promoter activity

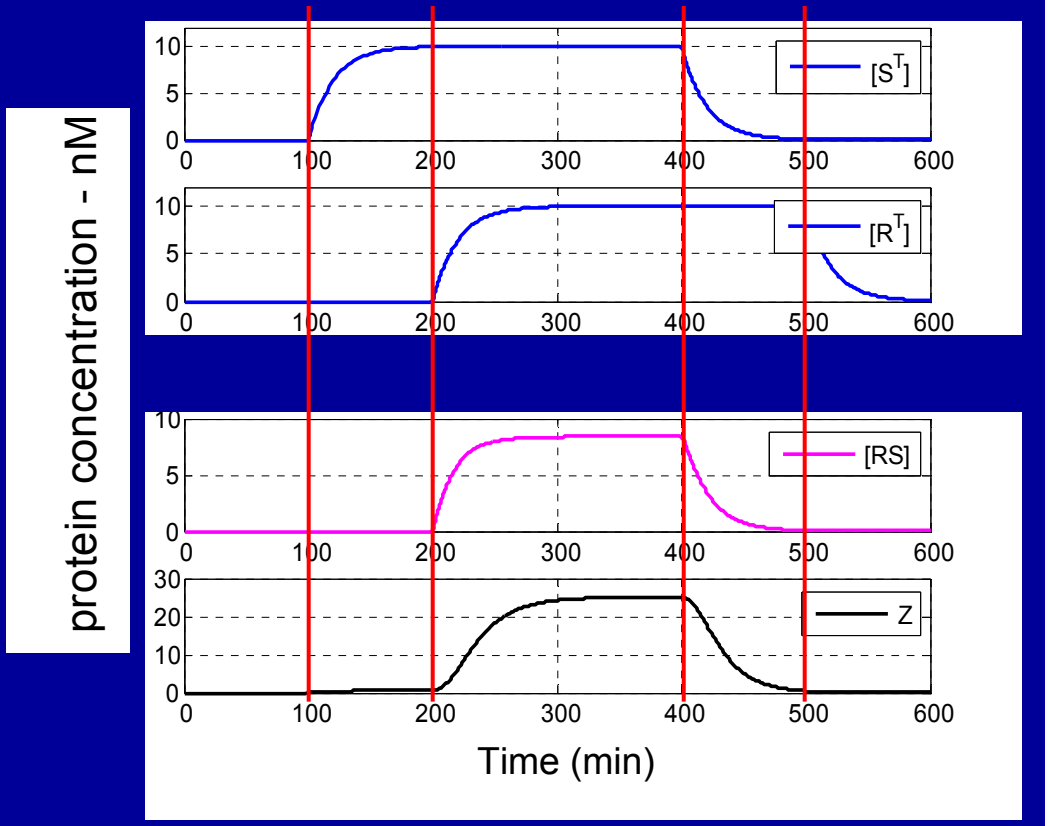



*In vivo* expression in *E.Coli* (MC4100 *ØhrpL-lacZ*) of various *hrp* constructs in *cis* (RS) or *trans* (R+S) or individually(R, S).



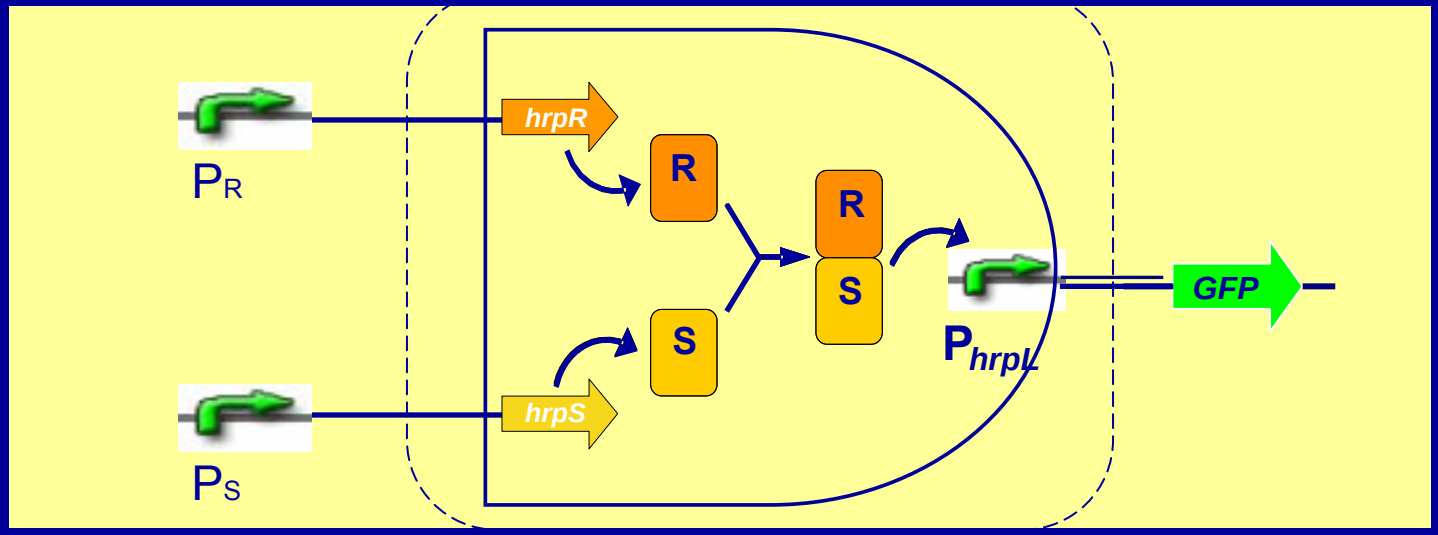
# Modelling Case1: *hrpL* regulated by 2 factors

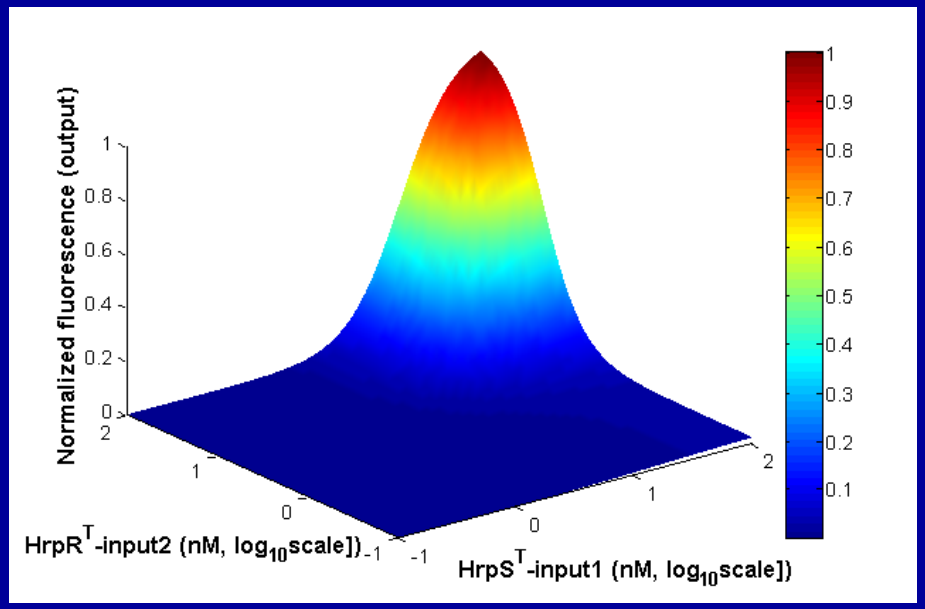



Simulation results: the dynamic evolution of protein concentrations

# A Modular AND Gate




| $P_R$ | $P_S$ | | pHrpL |
|---|---|---|---|
| 0 | 0 | | 0 |
| 0 | 1 | | 0 |
| 1 | 0 | | 0 |
| 1 | 1 | | 1 |

Logic Gates are the basic building blocks of all digital devices - counters, microprocessors, computers

There are strong parallels with Synthetic Chemistry in the 19th Century

Modern examples of natural dyes in the Mysore market in India

A.D. 1856 . . . . . N° 1984.

## Dyeing Fabrics.

LETTERS PATENT to William Henry Perkin, of King David Fort, in the Parish of Saint George in the East, in the County of Middlesex, Chemist, for the Invention of "PRODUCING A NEW COLORING MATTER FOR DYEING WITH A LILAC OR PURPLE COLOR STUFFS OF SILK, COTTON, WOOL, OR OTHER MATERIALS."

Sealed the 20th February 1857, and dated the 26th August 1856.

PROVISIONAL SPECIFICATION left by the said William Henry Perkin at the Office of the Commissioners of Patents, with his Petition, on the 26th August 1856.

I, WILLIAM HENRY PERKIN, do hereby declare the nature of the said Invention for "PRODUCING A NEW COLORING MATTER FOR DYEING WITH A LILAC OR PURPLE COLOR STUFFS OF SILK, COTTON, WOOL, OR OTHER MATERIALS," to be as follows:—

Equivalent proportions of sulphate of aniline and bichromate of potassa are to be dissolved in separate portions of hot water, and, when dissolved, they are to be mixed and stirred, which causes a black precipitate to form. After this mixture has stood for a few hours it is to be thrown on a filter, and the precipitate to be well washed with water, to free it from sulphate of potassa, and then dried. When dry it is to be boiled in coal-tar naptha, to extract a brown

William Henry Perkin -1856, the production of synthetic quinine from benzene

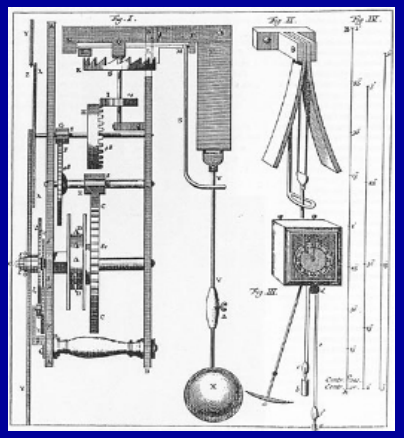
# Aspirin 1897

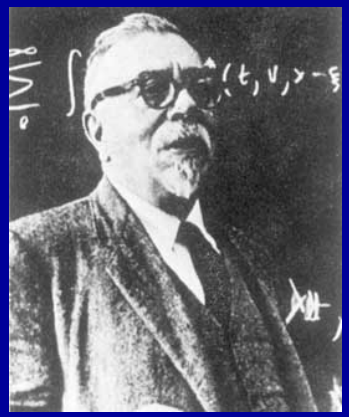

Chemist Felix Hoffmann, at Bayer in Germany


# Synthetic Rubber

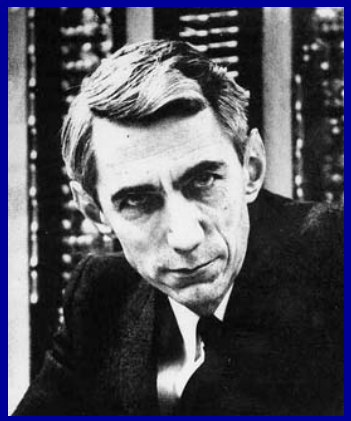
# Analogue Age → Digital Age → Biological Age

Huygens Pendulum Clock 1656. Accurate to better than 1 minute per day

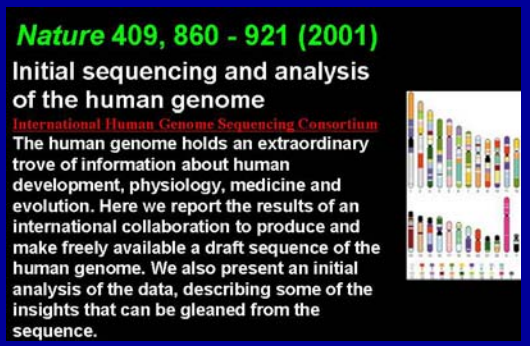




Norbert Wiener



Claude Shannon



# A New Industrial Revolution in the Making (?)

Synthetic Biology promises a shift comparable in importance to the ICT revolution with the power to revolutionise many sectors of the economy including:

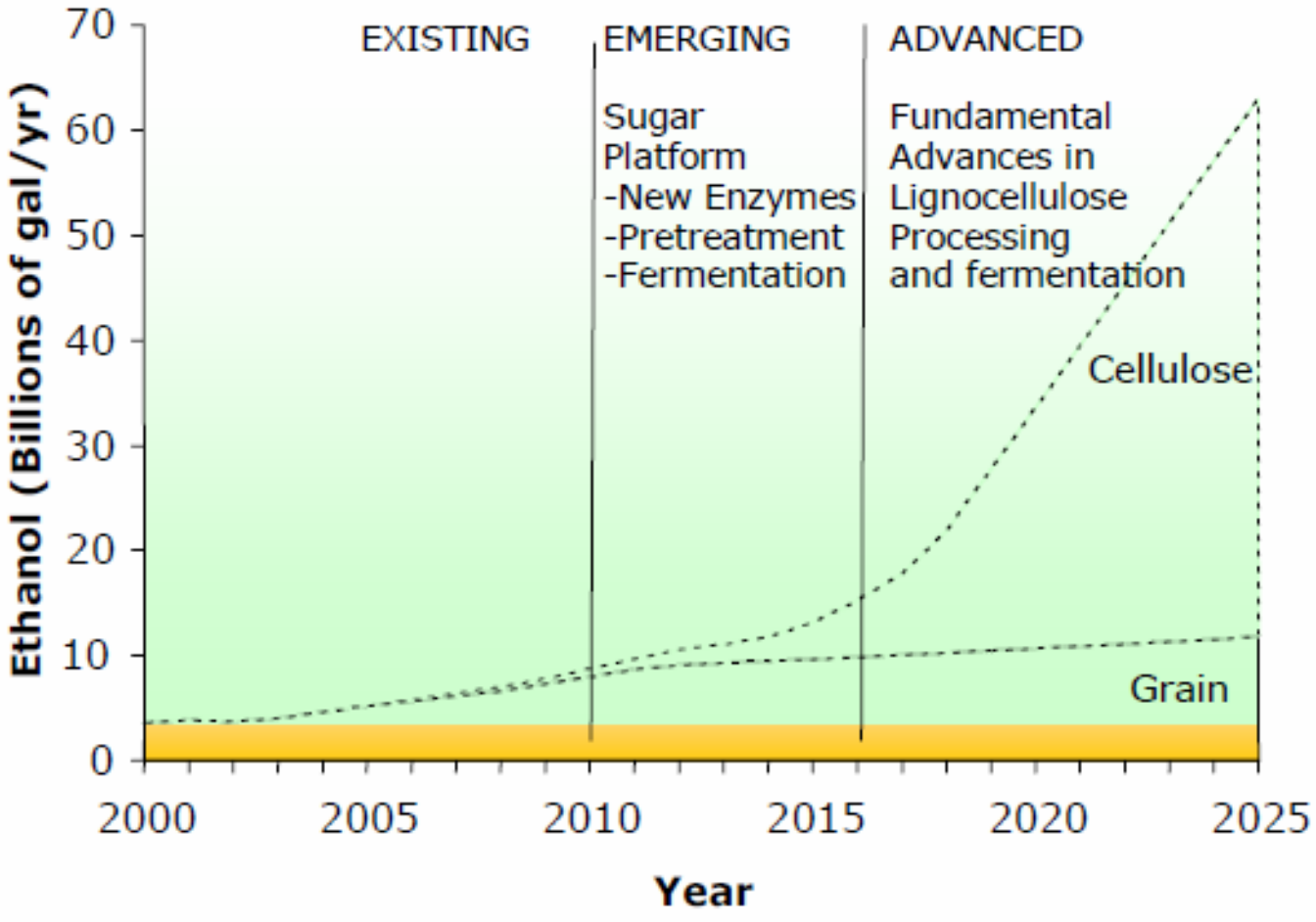
- Biofuels
- Biomaterials
- Medicines/Drugs/Vaccines
- Biosensors

# Some Industrial Examples

# The objective of synthetic biology is the industrialisation of biology

Engineering micro-organisms
to make Bio-diesel

# A DoE (US) Ethanol Vision




Modified from Richard Bain, NREL

# Example: Halophile energy from desalination

*Halobacterium halobium*

Thrives in waste brine from desalination

Engineered to produce isobutanol biopetrol from sunlight and $CO_2$

Provides an local source of energy for desalination

# Example: Heavy-metal biosensors for water

Arsenic, Antimony, Lead

Small molecules that are expensive to detect

Natural proteins can bind these

Microbial two-component signalling systems are modular

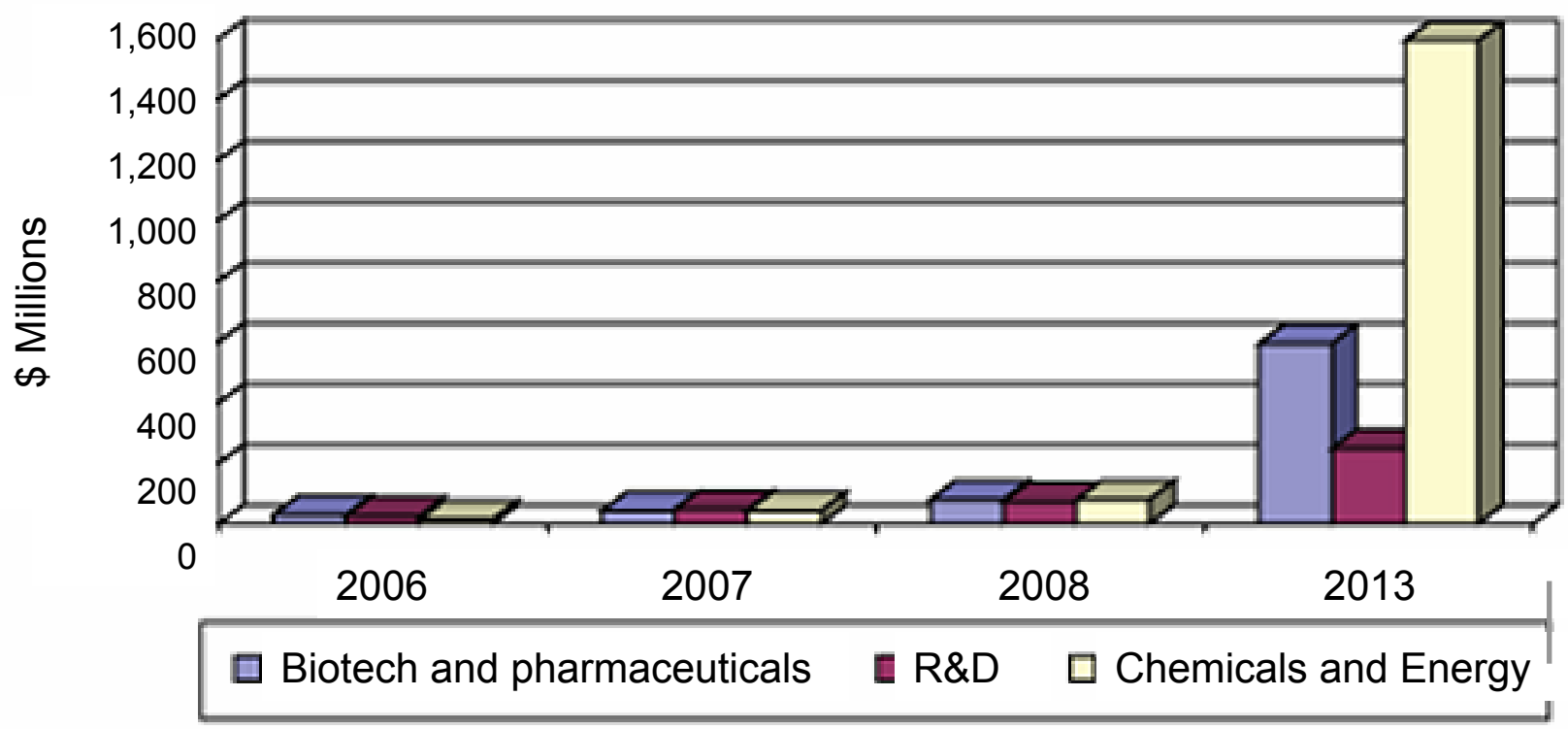
Bind – Detect – Signal

What microbes /organisms can be safely added to points in the water supply?

- Coliform bacteria – *E.coli*, *Citrobacter*
- Algae, pond weed plants

| Market | Segment | Associated Products and Areas |
|---|---|---|
| Medical devices | Tissue Engineering/Biomaterials | Medical Devices/implants |
| Pharmaceutical | Diagnostics/Biomarkers | Pharmaceutical |
| | Molecular imaging | Medical Contrast agents/imaging |
| | DNA Vaccines | Infectious diseases |
| | Drug synthesis (Improving synthesis of existing agents) | Pharma/ Bioprocessing /Biosynthesis |
| | Pharma-Cosmetic | Biosynthesis |
| Agroscience | Pesticide/Toxicity testing | |
| | Plant Breeding/Crop Yield | |
| | Food Quality Monitoring | Food Packaging |
| | Nutrition | Biosynthesis |
| Utilities | Environmental Monitoring | Water Supply/Bioterrorism etc |

## SUMMARY FIGURE
## GLOBAL VALUE OF SYNTHETIC BIOLOGY MARKET BY INDUSTRY 2006-2013
## ($ MILLIONS)




Source: BCC Research

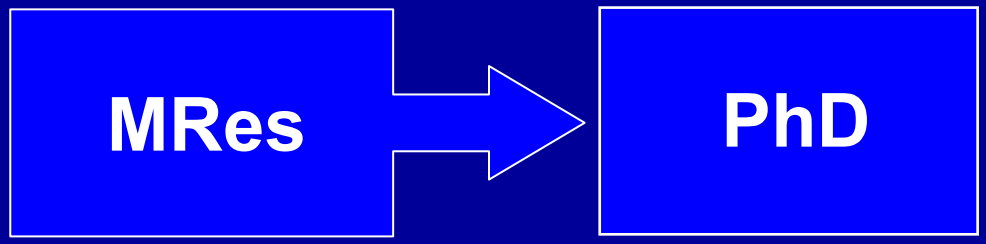
Report ID:BIO066A, Published: June 2009, Analyst: John Bergin

# Education and Training

# Undergraduate Training

- Final Year course in Synthetic Biology typically 15 students from engineering + 15 from biology
- iGEM (the international Genetically Engineered Machines Competition) – run by MIT

# Graduate Training




- The Imperial College (IoSSB) MRes started October 2008
- Ongoing PhD Programme

# iGEM 2009

Go Search

page discussion view source history teams Log in





## iGEM 2009 Jamboree

**October 31 to November 2, 2009**

Massachusetts Institute of Technology

Quick links:

Team abstracts
Team websites
Schedule
Campus Map
iGEM 2009 Jamboree results

### About iGEM

- What is iGEM?
- Previous iGEM competitions
- iGEM Headquarters
- Frequently Asked Questions
- iGEM Press Kit
- Join the iGEM Mailing List
- Sponsor iGEM

### iGEM Start to Finish

- Calendar of events
- Start a team
- Requirements
- iGEM 2009 Registration
- Spring workshops
- Summer News & Events
- The Jamboree

Add your iGEM 2009 **publicity**, **photos**, & **publications**

# iGEM
# The Need for European Funding

# Establishing European Collaboration in Synthetic Biology

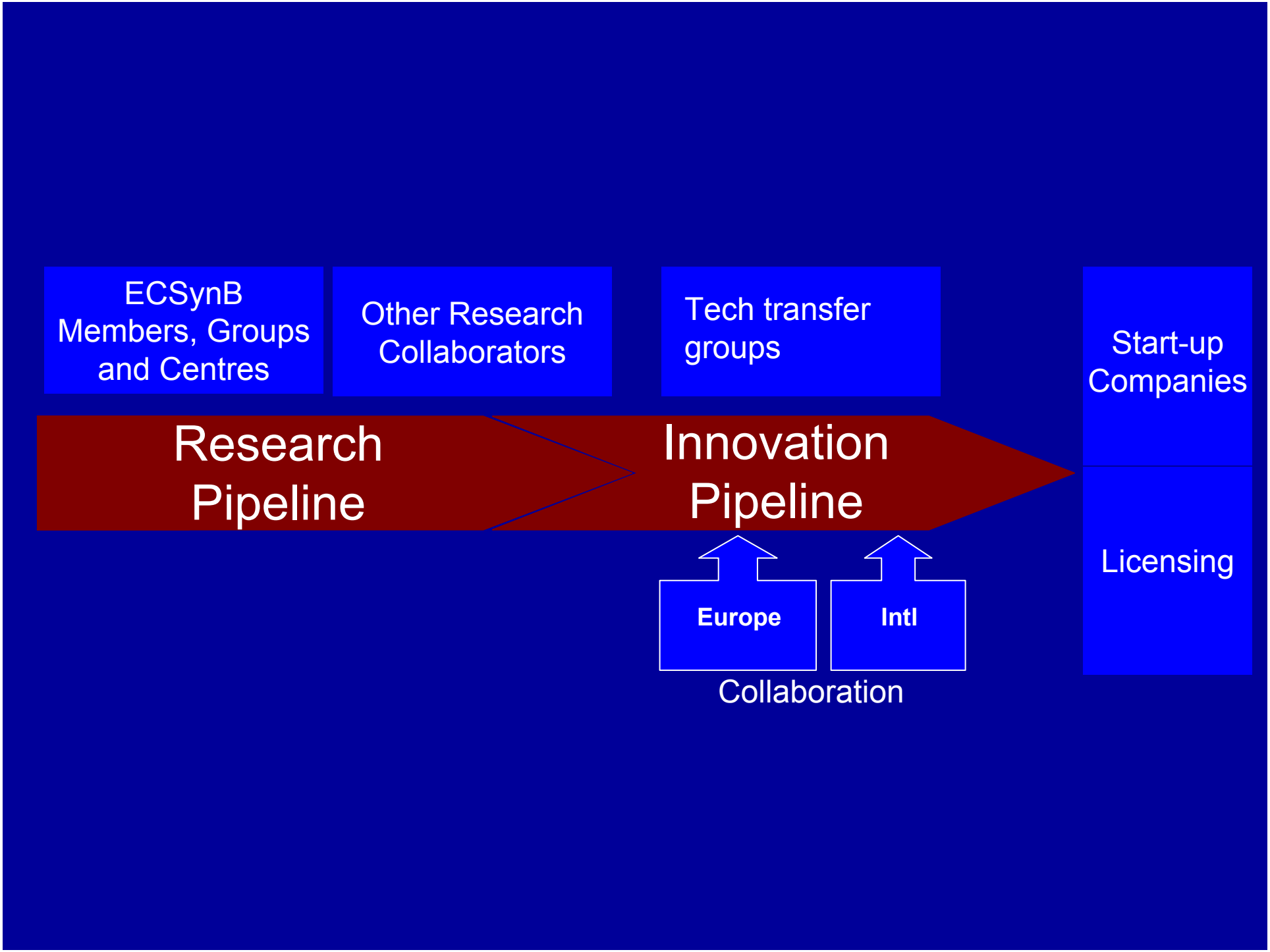
- What is required is leading European academic groups to work with industry
- Establishing a European Consortium
- Hub

# ECSynB - European Consortium for Synthetic Biology

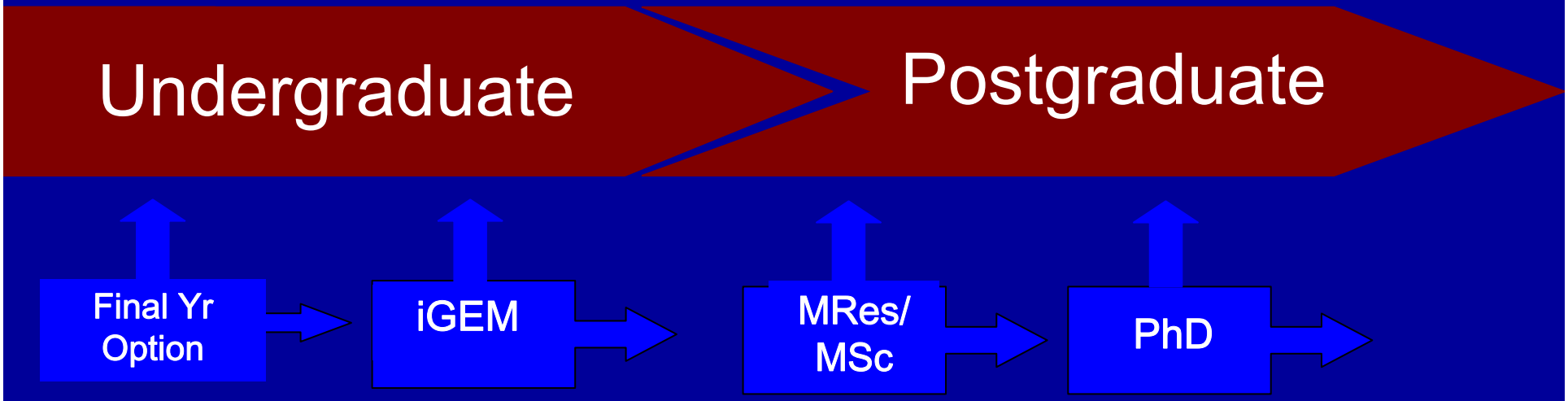
Phase 1. Undertake an audit of European Research Activity (academic and industrial) – 6 months

Phase 2. Undertake a more general audit to develop a strategic plan for Europe (use Tessy and other reports)

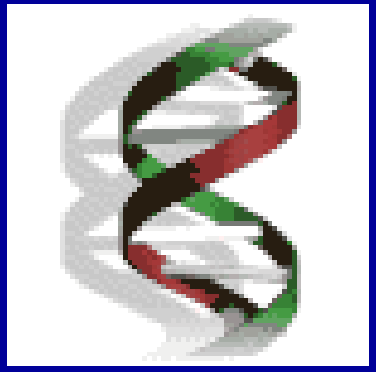
Phase 3. Identify Grand Challenges


ECSynB Members, Groups and Centres
Other Research Collaborators
Tech transfer groups
Start-up Companies
Research Pipeline
Innovation Pipeline
Licensing
Europe
Intl
Collaboration

# The Education Pipeline



# The End



This paper was produced for a meeting organized by Health & Consumers DG and represents the views of its author on the subject. These views have not been adopted or in any way approved by the Commission and should not be relied upon as a statement of the Commission's or Health & Consumers DG's views. The European Commission does not guarantee the accuracy of the data included in this paper, nor does it accept responsibility for any use made thereof.