Bioengineering

The Four Majors at UCSD

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Shu Chien-Gene Lay Department of Bioengineering

Simplified History of Bioengineering Departments

- Early ones grew out of one of:
  - Electrical, Mechanical or Chemical Engineering
- Hence they emphasize these base engineering disciplines – "**MEDTECH**"
- For the last 20 years the emphasis has shifted to
  - biological tissues: tissue engineering
  - controlling gene expression: genetic engineering / synthetic biology
  - computational modeling: bioinformatics & systems bioengineering
- New:
  - Informatics in genomics and in health care
  - Everything is a system – molecular level ("systems biology"), physiological systems, hospital systems, medical systems, …

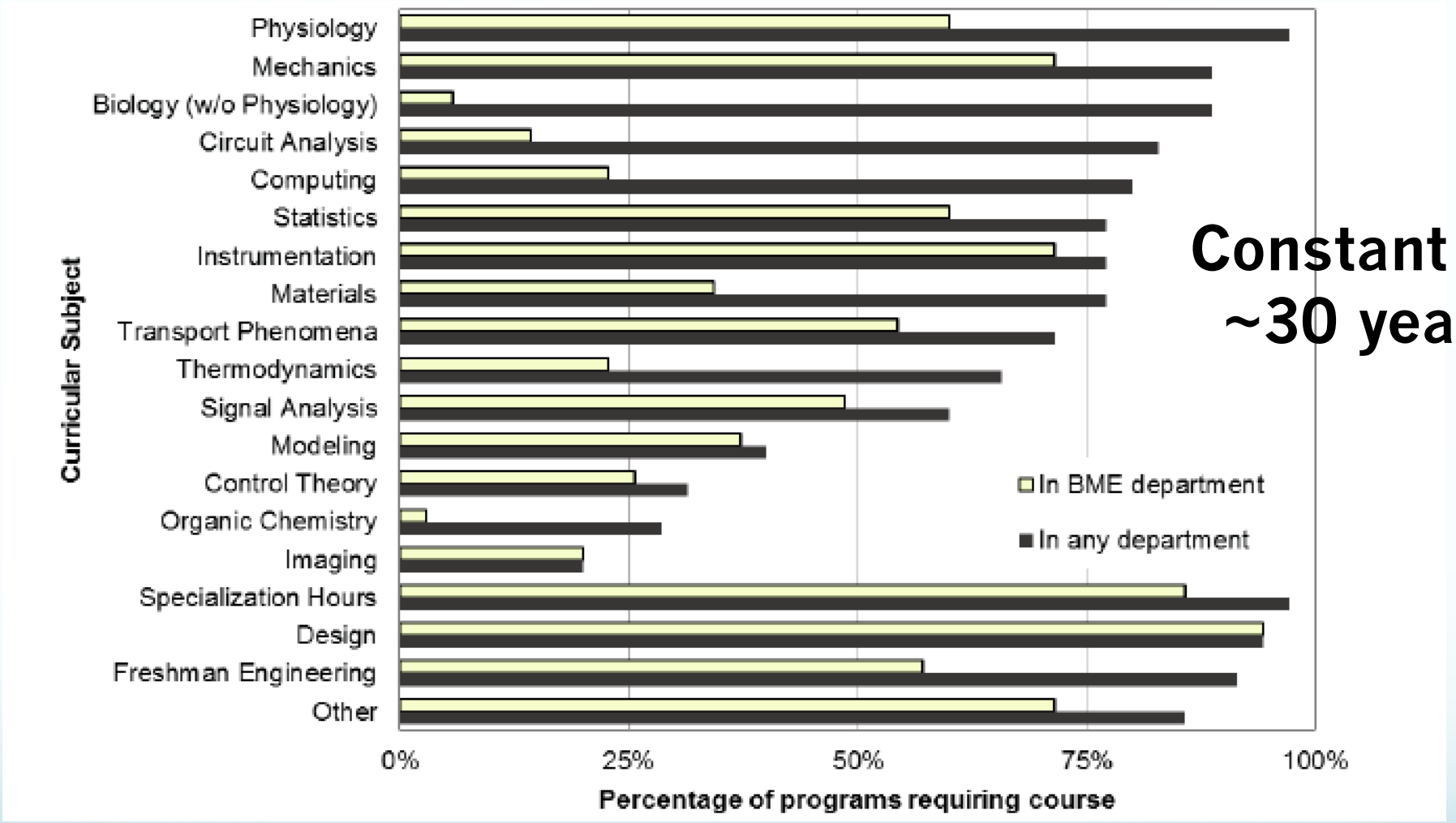
UCSD UG Majors Reflect the Changes

- **Bioengineering**: original major is strongly rooted in **mechanics** especially as applied to cardiac and tissues
  - Aligns closely with **"MEDTECH"** (with more electronics/instrumentation)
- **Biotechnology**: reflects continuum from **chemical/biochemical** engineering to materials to **tissues** to **molecular** engineering
- **Bioinformatics**: **computation for genomics** and molecular biology, "wet" biological systems
- **Biosystems:** mixture of **EE, modeling, computation** – substantial part of medical market – also good prep for systems biology modeling, machine learning, ...

Nationally:
Typical BME Coursework For
”MED TECH”

- Engineering Prep
  - Calculus thru DifEQ; Physics; Chem; Computing
- Base Engineering
  - Mechanics, Materials, Transport, Thermo, Circuits
- Base Biology
  - Physiology, Biology, Organic
- Advanced Engineering
  - Instrumentation, Signals and/or Imaging, Control
- Specialization (Electrical, Instrumentation, Imaging, Materials, Mechanical, Tissue, Premed)
- Design

BME "MEDTECH"Curricula Across the USA



Constant for ~30 years

Gatchell and Linsenmeier: 121st ASEE Conf 2014 VaNTH Biomedical Engineering Key Content Survey, Part Two. The 2nd Step in a Delphi Study to determine the core undergraduate BME curriculum

Common Coursework for UCSD Bioengineering

- Calculus thru DifEq and Linear Algebra
- Chemistry: 2 quarters plus lab; Molecular Chemistry
- Physics: 3 quarters plus one or two labs
- Biology: Cellular, Physiology
- Programming, Statistical Design
- Senior Design Sequence: total of 10 credits over 4 quarters

Bioengineering: Bioengineering

- Physics/biomechanics heavy: traditional and original bioengineering field and discipline
- Designed for prosthetics development and medical device development
- Examples of research:
  - Dr. Andrew McCulloch (multiscale cardiac modeling and experimentation)
  - Dr. Pedro Cabrales (regulation of cellular and metabolic processes)

Bioengineering Major: Coursework

- **Biomechanics thru Mass Transfer (4 courses)**
- **Physiology (2 courses + lab)**
- **Instrumentation (5 courses including lab)**
- **Control, modeling, computation (4 courses)**
- **Biomaterials (1 course)**

Students know a lot about mechanical systems, materials, instrumentation, physiology and modeling.

Bioengineering Major: Related Faculty*

Pedro Cabrales
Functional Cardiovascular Engineering

Shu Chien
Cardiovascular Mechanics

Marcos Intaglietta
Micro-hemodynamics

Elliott McVeigh
Cardiovascular Imaging and Therapy

Geert Schmid-Schoenbein
Molecular/Cellular Biomechanics

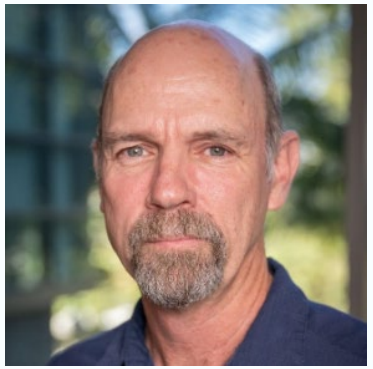
Ratneshwar Lal
Nano-biotechnology

Francisco Contijoch
Cardiovascular Imaging for Disease Assessment

***Faculty work in multiple areas**

Bioengineering Major: Related Faculty

Kevin King (MD, PhD)
Cardiology and Bioengineering



Andrew McCulloch
Computational Cardiac Mechanics

Gabe Silva
Neural Engineering
Visual neuroscience
nanotechnologies

Daniela Valdez-Jasso
Biomechanics, cardiovascular

John Watson
Entrepreneurism
Clinical Trials
Cardiovascular

*** Faculty work in multiple areas**

Bioengineering: Biotechnology

- More chemistry-based/cellular components
- Designed for tissue and stem cell engineering, but also for biochemically based sensors (e.g. glucose detection) and genetic engineering
- Examples of research:
  - Dr. Karen Christman (injectable biomaterials for tissue repair and regeneration);
  - Dr. Stephanie Fraley (immune disease detection and cancer intervention)
  - Dr. Adam Engler (stem cell research)

UCSD BIO TECH

- **Organic Chem (2 courses)**
- **Biomolecular/Biochemical Engineering (6 courses)**
- **Mass Transfer/Fluid Mechanics (2 courses)**
- **Control, modeling, computation (4 courses)**
- **Biomaterials and Cell/Tissue (2 courses)**
- **Genetics (1 course)**

Students know a lot about genetic control, bioseparations, cell culture, recombinant technologies, RNA/DNA analytic and synthetic technologies

Biotechnology Major: Related Faculty

Karen Christman
Regenerative Medicine
Tissue Engineering
Biomaterials

Stephanie Fraley
Immune Modulated Disease, Systems Biology& Technology

Prashant Mali
Synthetic Biology, Regenerative Medicine, Stem Cells

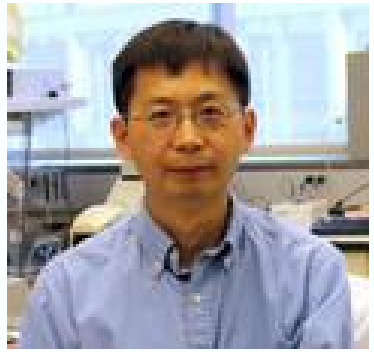
Adam Engler
Stem Cells,
“Disease in a Dish”,
Biomaterials

Brian Aguado
Biomaterials, tissue engineering, precision medicine, sex differences, immunoengineering

*** Faculty work in multiple areas**

Biotechnology Major: Related Faculty

Christian Metallo
Systems Biology, Metabolism / Modeling Cancer



Kun Zhang
Integrative Genomics Single cell genomics, technologies

Lingyan Shi
Laser based microscopy for subcellular studies related to cancer, metabolism, brain

Robert Sah
Cartilage Repair, Tissue Engineering

Yingxiao Wang
Molecular Engineering, Fluorescence Markers of Subcellular function

Ester Kwon
Nanotechnology, Neural and Bioinspired Materials, Drug Delivery

*** Faculty work in multiple areas**

Biotechnology Major: Related Faculty

Bogdan Bintu
Gene regulation from the nucleus to tissue organization

Reem Khojah
Education, magnetic control to automate single cell analyses

Microbiome
Molecular Biology

Viva Kravets
Networks of insulin producing cells

Yingxiao Wang
Molecular Engineering, Fluorescence Markers of Subcellular function

Ester Kwon
Nanotechnology, Neural and Bioinspired Materials, Drug Delivery

*** Faculty work in multiple areas**

Bioengineering: Bioinformatics

- Computational Biology: heavy emphasis on programming and data modeling and mapping
- Genome mapping and data mining
- Examples of research:
  - Dr. Shankar Subramaniam (protein interaction networks between cells);
  - Dr. Sheng Zhong (computational genomics and modeling of gene networks);
  - Dr. Bernhard Palsson (Reconstruction of genetic circuits and genome-scale models of complex cellular processes)

Bioinformatics Major: Coursework

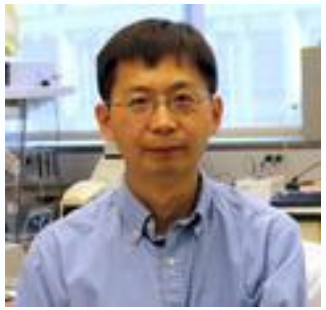
- **Organic Chem (1 course)**
- **Biomolecular Engineering (1 course)**
- **Molecular and Genomic Data and Sequening (4 courses_**
- **Control, modeling, computation (4 courses)**
- **Genetics and Cell Biology (4 courses)**
- **Advanced Computation (4 courses)**

Students are very capable of all kinds of “omic” data analysis

Bioinformatics Major: Related Faculty

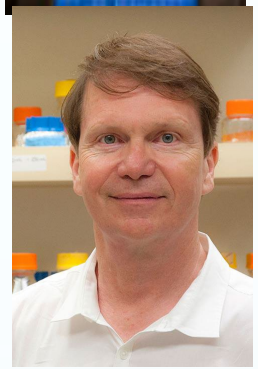
Jeff Hasty
Computational Genomics, Gene Regulatory Networks

Christian Metallo
Systems Biology, Metabolism / Modeling
Cancer



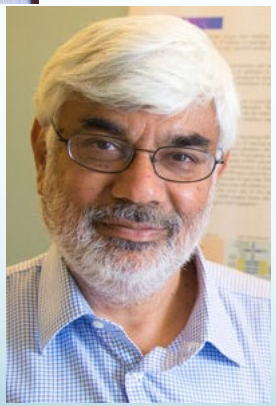
Kun Zhang
Integrative Genomics
Single cell genomics, technologies

Ben Smarr
Time series analysis in biological systems, data science



Bernhard Palsson
Genetic Circuits, Genome Scale Modeling

Sheng Zhong
Computational Genomics



Shankar Subramaniam
Bioinformatics, Systems Biology and Medicine

Ludmil Alexandrov
“Omics” for Cancer Detection

*** Faculty work in multiple areas**

Bioengineering: BioSystems

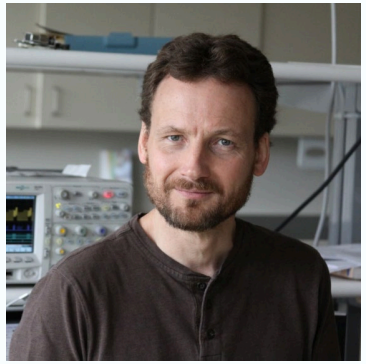
- Understanding and Modeling Multidimensional Dynamic Systems, whether the scale be molecular, physiological, or health care
- Modeling and Simulation Optimization Dynamics
  Measurement and Systems Analysis Statistical Analysis
- Examples of research:
  - Dr. Shankar Subramaniam (modeling of cellular networks);
  - Dr. Gert Cauwenberghs (biomedical integrated circuits and systems as it applies to neuroscience);

Biosystems Major: Coursework

- **Mechanics (1 course)**
- **Biomolecular Engineering (2 course)**
- **Circuits, Signals, Control, Probability, Modeling (7 courses)**
- **Instrumentation (3 courses including lab)**
- **Physiology (3 courses)**

Students are very well prepared for understanding analytical models across multiple scales and problems
Every Engineering Major has a Systems Concentration
Every industry is inherently systems oriented

Biosystems Major: Related Faculty



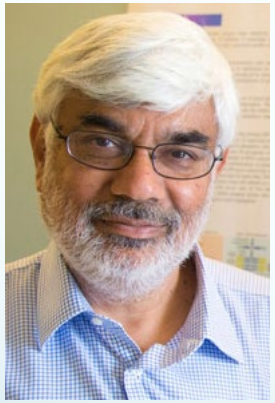
Gert Cauwenberghs
Neural Engineering
Circuits/Instrumentation

Kevin King (MD, PhD)
Cardiology and
Bioengineering

Gabe Silva
Neural
Engineering
Visual
neuroscience
nanotechnologies

Bernhard Palsson
Genetic Circuits,
Genome Scale
Modeling

Bruce Wheeler
Neural Engineering,
Signal Processing,
Microfabrication
Undergraduate
Education



Shankar Subramaniam
Bioinformatics,
Systems Biology and Medicine

Ben Smarr
Time series analysis in
biological systems,
data science

Alyssa Taylor
Undergraduate
Education

***Faculty work in mutiple areas**

Following Slides

- **Key Areas of Bioengineering**
- **Which Majors are Best Prepared for Each**

PRACTICAL APPLICATIONS

- **Clinical Engineering** – managing technology in hospitals
  - **Bioengineering, Biosystems; ECE, MAE**
  - Certificates: American College of Clinical Engineering – there is no clinical engineering UG degree! business skills a plus
  - Now known as Healthcare Technology Management
- **Diagnostic & Therapeutic Systems** – improve instrumentation, lab clinical, physiological, data
  - **Bioengineering, Biosystems; ECE, MAE**
  - Includes clinical decision making support
  - Industry – not an academic discipline
- **Rehabilitation Engineering** – augmentative technologies
  - **Bioengineering, Biosystems; ECE; MAE; Rehabilitation specialty programs**
  - Will need to work/study in Rehabilitation facilities
  - Growing use of Smart Houses and Fit-Bit devices; wheelchairs
  - Performance Enhancement?

STARTING FROM PHYSIOLOGY

- **Cardiac Bioengineering** – cardiovascular disease modeling and imaging; therapeutics
  - **Bioengineering, Biotechnology; MAE; ECE**
  - Multiscale modeling; increasing emphasis on imaging; device technologies (valves, artificial hearts) are sophisticated; move toward biomolecular & tissue
  - Very strong research at UCSD
- **Neural Engineering** – imaging, brain-computer interface
  - **Bioengineering, Biosystems; ECE; CSE; Neuroscience**
  - Neuroscience is a huge area and exceptional at UCSD
- **Physiological System Modeling** -- all other systems
  - **Bioengineering, Biosystems; Physiology; CompSci**

ELECTRONICS TECHNOLOGY AND INSTRUMENTATION

- **Instrumentation Sensors and Measurement**
  - **Biosystems, Bioengineering; ECE; CSE; Nano; BChem**
  - Powerful enabler of much of medical technology
  - A real plus if you add Biotechnology and bio/chemical/molecular sensing
- **Bio-signal Processing**
  - **Biosystems; ECE; CSE**
  - Common to much of instrumentation
- **Wearable Biomedical Sensors**
  - **Biosystems; ECE; CSE; Bioengineering; MAE; NanoE**
  - Explosion of electronics technology coupled with mostly physiologic measurements

BIOMEDICAL IMAGING

- **Biomedical Imaging** – MR, CT, Ultrasound, Nuclear Med
  - **Biosystems, Bioengineering; ECE; CSE; Physics**
  - Major Medical Modalities: Ultrasound, MRI, CT
  - **THE MOST IMPORTANT ENGINEERING CONTRIBUTION TO MEDICINE**
- **Biomedical Image Processing**
  - **Biosystems, Bioengineering; ECE; CSE; Physics**
  - You can do the processing independent of building the device
- **Radiology** – especially radioactive modalities
  - **Physics, Nuclear Engineering; Bioengineering**
  - Xray, Radiation Therapy, Positron Emission Tomography
- **Microscopies; Molecular Imaging**
  - **Biotechnology, Bioengineering; Biological Sciences; Physics; Biochem; Chem**
  - Tremendous innovation in physical microscopy technologies
  - Great growth in use of innovative biomolecules to augment images

MOLECULAR BIOLOGY MEETS COMPUTERS / INFORMATION

- **OMICS, OMICS, OMICS** … *fundamentals of how biology does information processing*
  - **Genomics** -- DNA is principal carrier of information
  - **Transcriptomics** – DNA to RNA
  - **Functional Genomics** – dynamics of gene and protein interactions
  - **Proteomics** – structure and large scale composition of proteins
  - **Metabolomics** – chemical processes within a cell – good match for computationally intensive modeling
- **Knowledge / Skill Base**
  - **Molecular Biology / Biochemistry / Computer Science**
- **Who**
  - **Bioinfo (taught by BioE, CSE, Biology); Data Science**
  - Big area of growth

MEDICINE MEETS COMPUTERS

- **Medical and Health Informatics**
  - **Bioinformatics, Biosystems; CSE; ECE; Data Science**
  - **Largest/fastest growing of all biomedical engineering areas – perhaps 50% of all BME jobs**
  - Data mining, analysis of all kinds of medical data
- **Information Technology** – wireless, wearables, analytics
  - **Bioinformatics, Biosystems; CSE; ECE; Data Science**
  - Also Artificial intelligence, ”Big Data”, Patient Health Care Records
- **Telemedicine –** “telehealth” or “e-health”
  - **Biosystems, Bioengineering; CSE; ECE**
  - Remote delivery in third world countries; remote doc at urgent care clinics

MECHANICS MEETS BIOLOGY AND MEDICINE

- **Biomechanics**
  - **Bioengineering; BTech; MAE; Materials Science**
  - Orthopedics, knee/hip implants; artificial hearts; blood circulation
  - Tremendous need to mix biomechanics and biomaterials
- **Robotics in Surgery**
  - **Bioengineering, Biosystems; MAE; CSE; ECE**
  - Includes heavy reliance on imaging and artificial intelligence
- **Biorobotics**
  - **Bioengineering; Biosystems; ECE; MAE; CSE**
  - Biomimetic Devices (e.g. exoskeletons)
  - Rehabilitation Assist Devices

MATERIALS GO VERY SMALL

- **Micro / Nano Technology**
  - **Nano Engineering; ECE**
  - Fabrication of devices of the same scale as cells and large biomolecules
- **BioMEMS** = Bio Micro Electro Mechanical System
  - **Nano Engineering; ECE; Biotechnology; Bioengineering**
  - Integration of micro/nano technology and biotechnology
  - Microfluidics; many “Lab on Chip” reactions come from biotechnology
- **Biomaterials**
  - **Biotechnology; Materials Science; Nano Engineering**
  - Customize materials to promote tissue responses (or to be inert); sutures
  - Essential to all kinds of medical products; **HUGELY IMPORTANT FIELD**

CHEMICAL ENGINEERING APPROACHES

- **Biotechnology**
  - **Biotechnology; Chemical Engineering; Nano Engineering**
  - Using microbial organisms to produce products (insulin, yeast, alcohol, commercial non-biological chemicals)
  - Novel DNA engineering techniques to correct genetic defects
- **Drug Delivery**
  - **Biotechnology; Chemical Engineering; Nano Engineering**
  - Integration of micro/nano technology and biotechnology
  - Microfluidics, “Lab on Chip”
  - Many “Lab on Chip” reactions come from biotechnology
- **Biofuels**
  - **BTech; Agriculture Ag Engr; ChemE; Chemistry**
  - Wouldn’t it be wonderful to ”grow your gasoline”

BIOLOGY GOES ENGINEERING

- **Tissue Engineering**
  - **Biology; BTech; Bioeng; Chem E; Nano**
  - Growing new tissues and organs
  - Very Exciting science
  - Exceptionally compelling applications (replace your damaged cartilage!)
  - Industry is still developing
- **Cellular and Molecular Biomechanics**
  - **BTech; Bioeng; Biology; Chem E; Nano E**
  - Mechanical properties of cells and substrates have tremendous impact on cell behavior and phenotype
  - Can we harness this?
  - Still a science and not an industry

ENGINEERING THE NEW BIOLOGY

- **Genetic Engineering and Synthetic Biology**
  - **Biotechnology; Molecular Biology**
  - The **MOST SPECTACULAR AREA** of BIOTECHNOLOGY
  - Beginning to impact many other areas – genetic diseases, crop production, anti-cancer drugs
  - Is it engineering or is it molecular biology? Or how soon will BS level Bioengineers be employed to do genetic engineering designs?