URC CARE

UCLA
Undergraduate Research Center
Center for Academic and Research Excellence

"Genetic Engineering New Crops: Importance for Food, Fuel, and Sustainable Crops"

Bob Goldberg

9/23/08

Today's Headlines

A Global Need for Grain That Farms Can't Fill

Published: March 9, 2008

High Rice Cost Creating Fears of Asia Unrest

By KEITH BRADSHER

Published: March 29, 2008

THE FOOD CHAIN

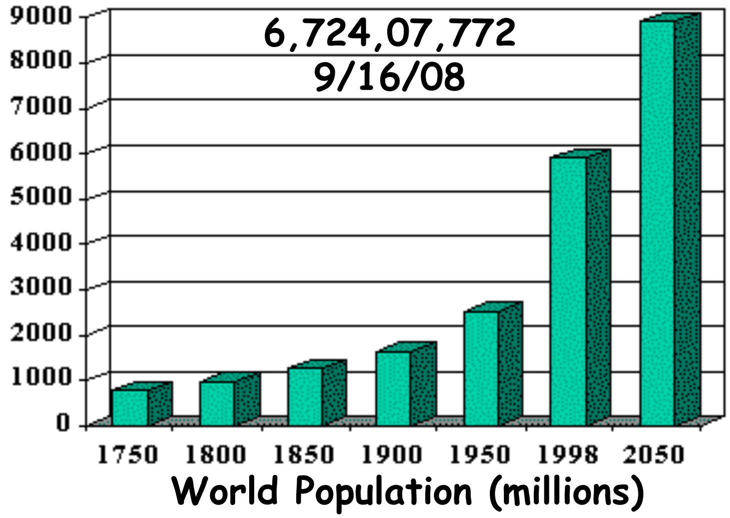
A Drought in Australia, a Global Shortage of Rice

Across Globe, Empty Bellies Bring Rising Anger

updated 10:42 p.m. EDT, Mon April 14, 2008

Riots, instability spread as food prices skyrocket

We Face Challenges In Agriculture Even Greater Than Those in Today's Headlines

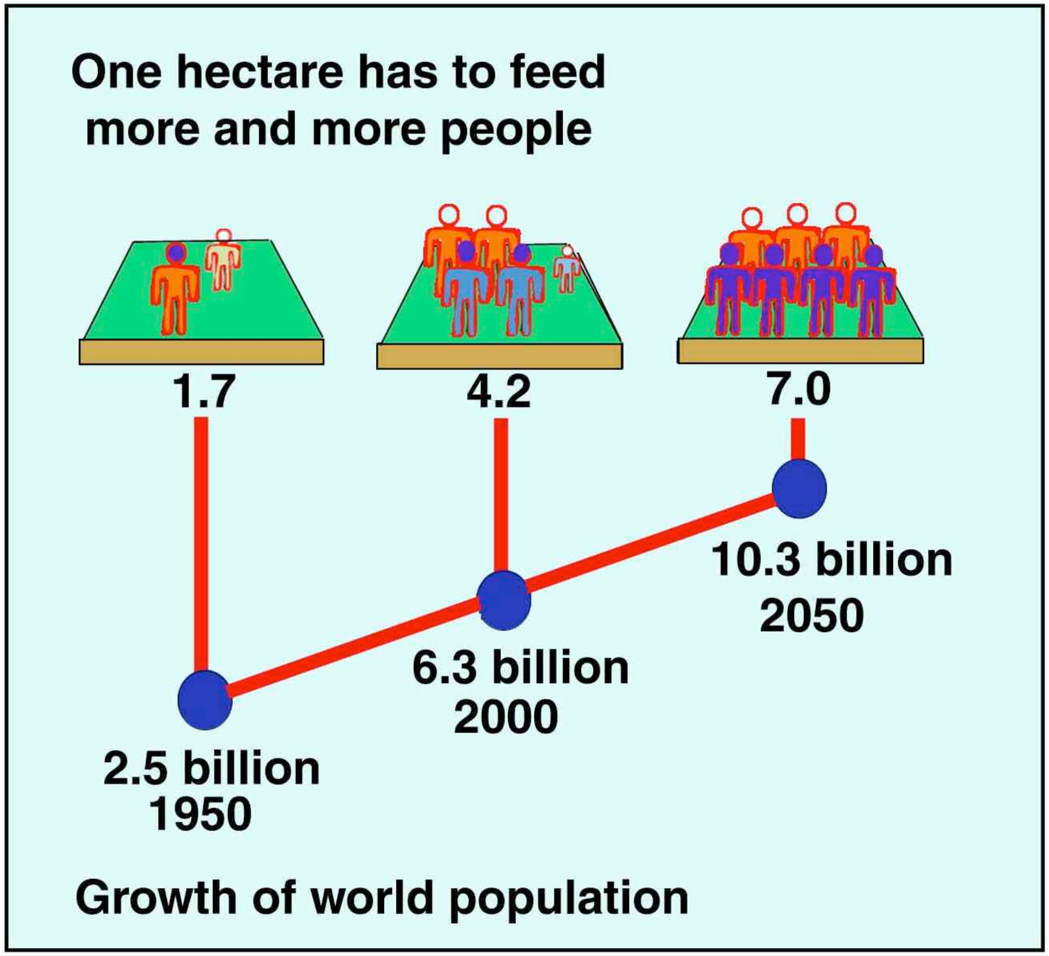


OVER THE NEXT 50 YEARS WE WILL NEED TO <u>PRODUCE MORE FOOD</u> THAN IN THE WHOLE OF HUMAN HISTORY

AND DO IT WITH FEWER INPUTS ON LESS ARABLE LAND!!!!

CROP YIELDS NEED TO BE INCREASED SIGNIFICANTLY!!

There is a Limited Amount of Land For Agriculture

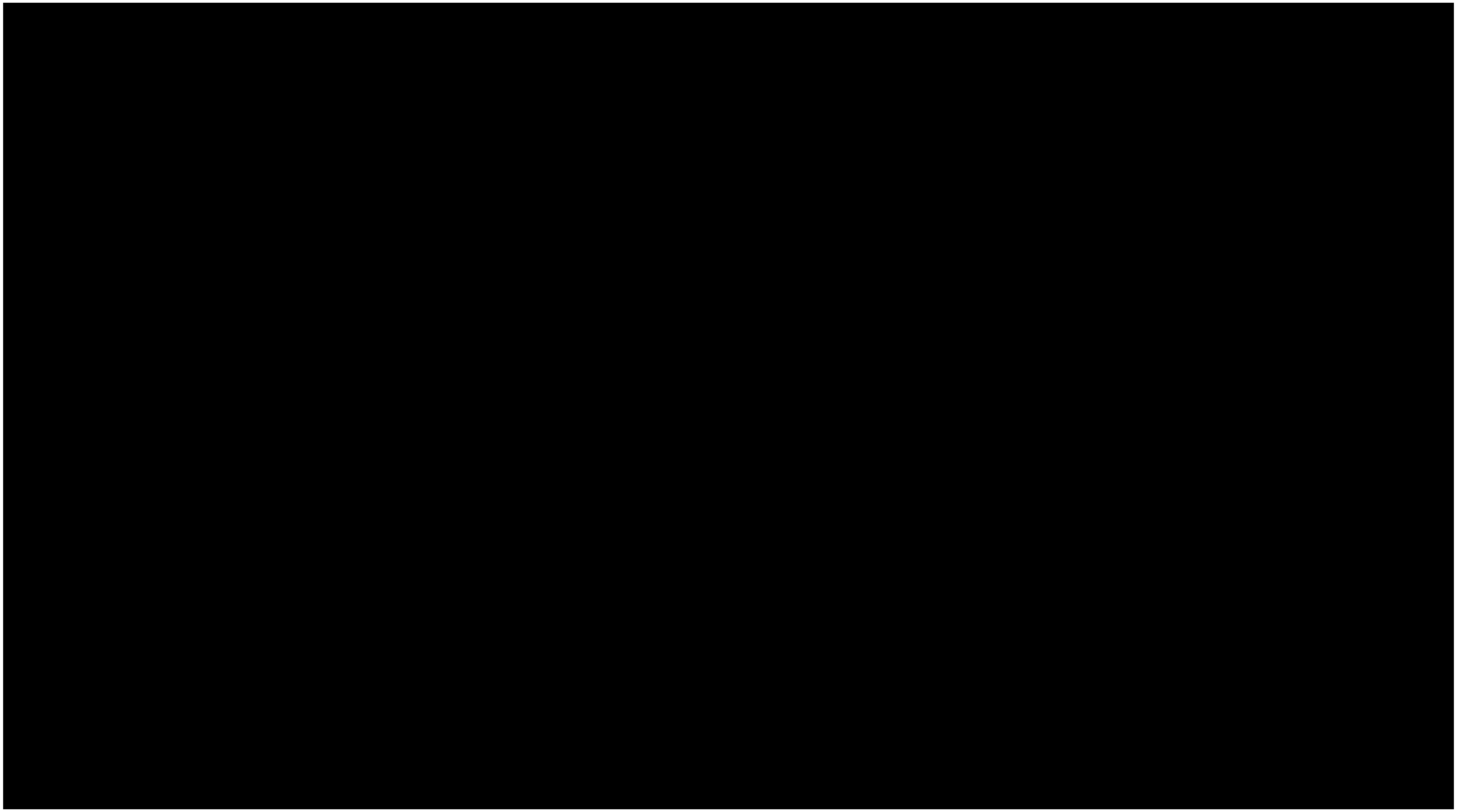


NOTE:
More Yield per
Acre Leaves
More Land
for Nature!!!!!

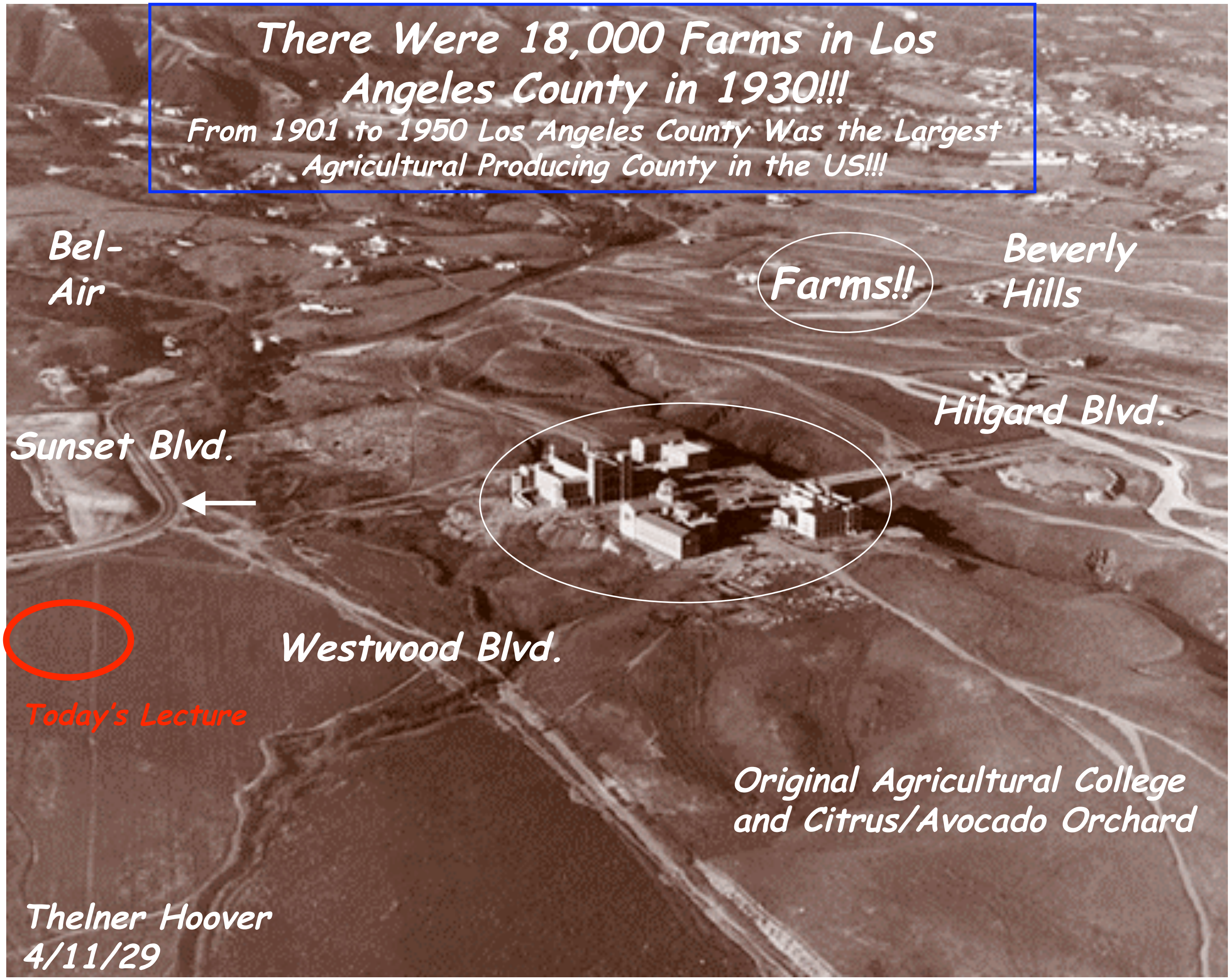
Without Increases in Crop Yield We Will Need to Farm
Every "Square Inch" of Land on the Earth To Satisfy Crop Demand

ADDING TO THE CHALLENGE TO PRODUCE SUFFICIENT CROPS….

And…….There's Also A Problem With Using Land For Energy Production………………



Aerial Photograph of UCLA in 1929




Aerial Photograph of UCLA in 2008
N
Bel-
Air
Beverly
Hills
Former Farms
Sunset Blvd.
Hilgard Blvd.
Original Agricultural College
and Citrus/Avocado Orchard
Westwood Blvd.
Image © 2007 Sanborn
Technologies
9/23/08
Google


How Will Crop Yields Be Increased?
As We Always Have………..
By Using State-of-the-Art Science & Technology

And By Using a Variety of Approaches to Identify Genes and Processes That Will Help Increase Crop Yields and Food Production Significantly in the 21st Century

Yield (Developmental Traits)

- Seed Number
- Seed Size
- Growth Rate
- Organ Size (More Seeds)
- Plant Architecture
- Flowering Time
- Senescence
- Maturity
- Stature

Yield (Stress Traits)

- Nutrient Uptake
- Drought Resistance
- Heat Resistance
- Cold Tolerance
- Salt Tolerance
- Shade Tolerance
- Disease Resistance

From "Low-Tech" to High-Tech

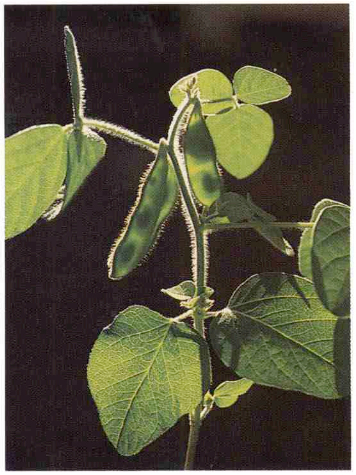
From Lab to Improved Seeds For Farmers

…….And Use Breeding and Genetic Engineering to Introduce These "Yield" Genes Into Existing Crops

Optimal Flowering Time

Seeds Without Fertilization

Hybrids



High Photosynthetic Efficiency

Drought Resistant

Pathogen Resistant

Efficient Uptake of Micronutrients

High Yields Under Suboptimal Conditions

Reduced Pod Shattering

Architecture Designed For Specific Growth Conditions

More Seeds

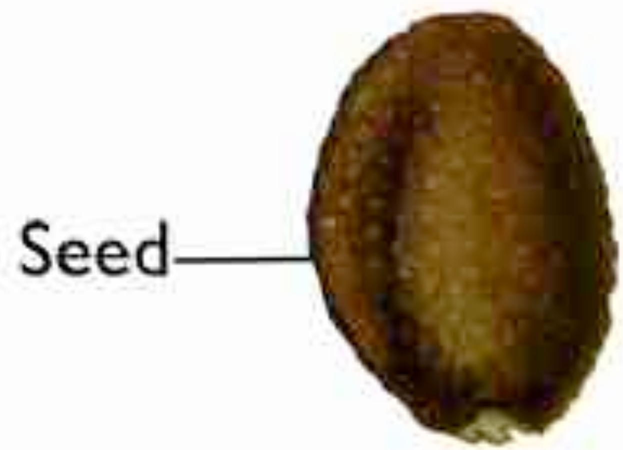
Bigger Seeds

Seeds Optimal For Human/Animal Health & Nutrition

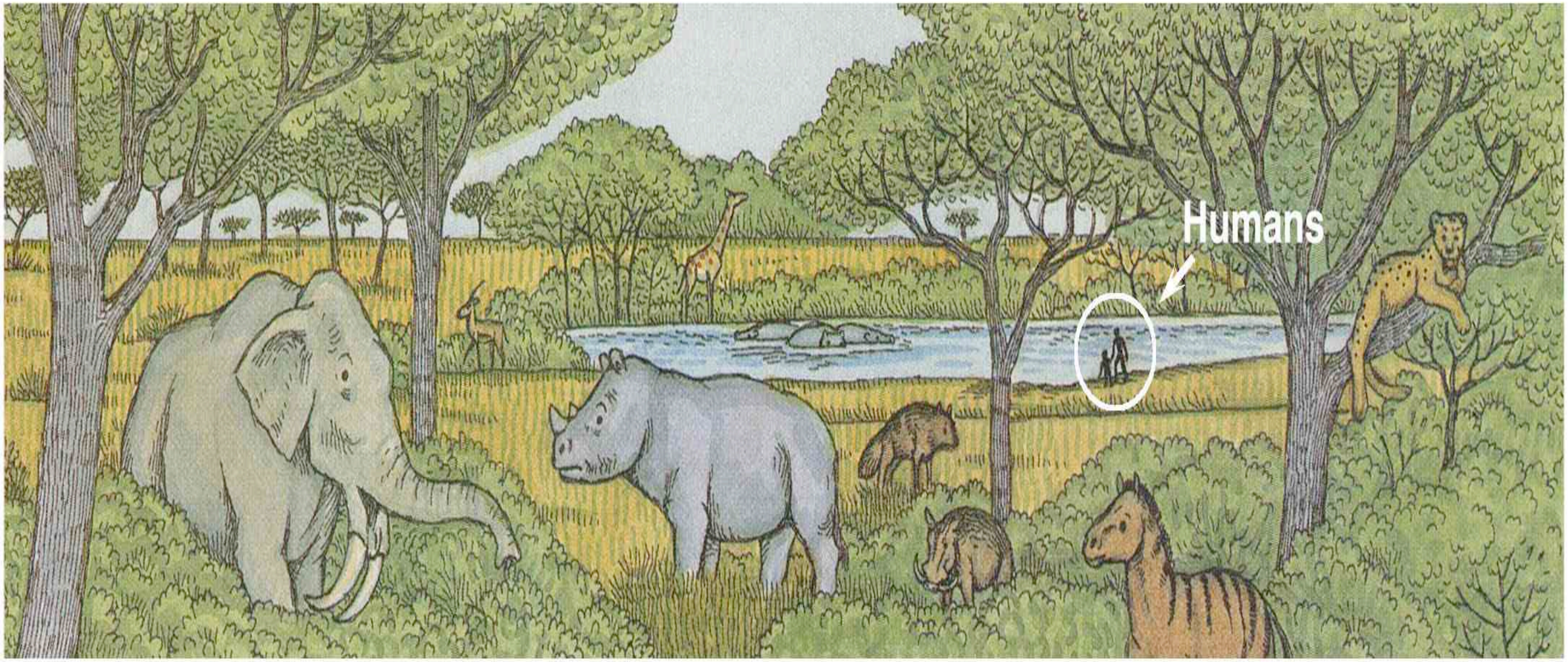
Ability to Fix Nitrogen

This WILL Happen……Sooner Than Later!

In the Beginning....



Early Humans Faced Major Challenges Finding Food



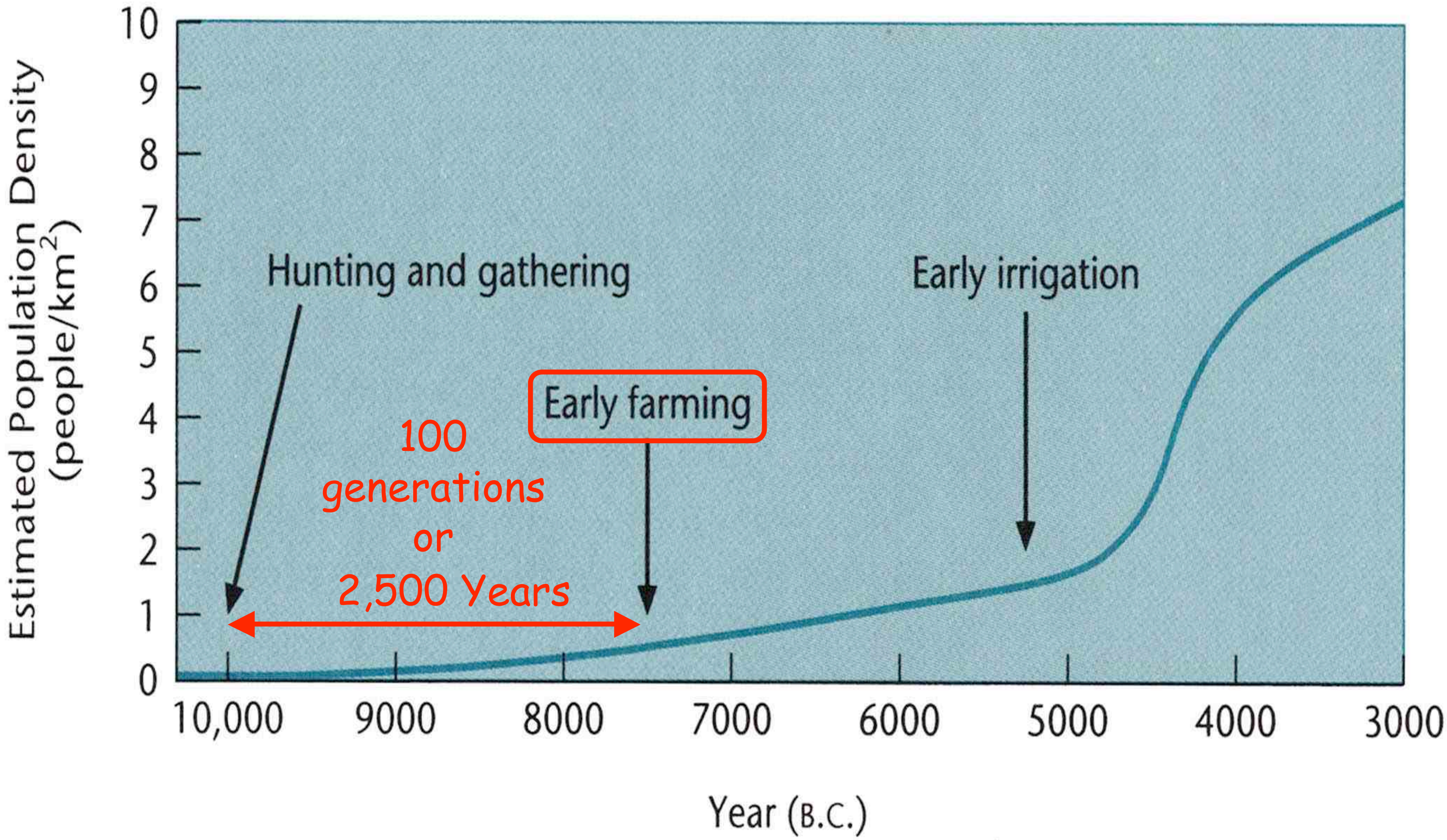
Gazella Giraffa Hippopotamidae Australopithecus

Deinotherium Ceratotherium Hyaenidae Nyanzachoerus Hipparion Machairodontinae

AROUND SIX MILLION YEARS AGO | LOWER LOTHAGAMIAN (LOWER PLIOCENE) | FIVE MILLION YEARS AGO

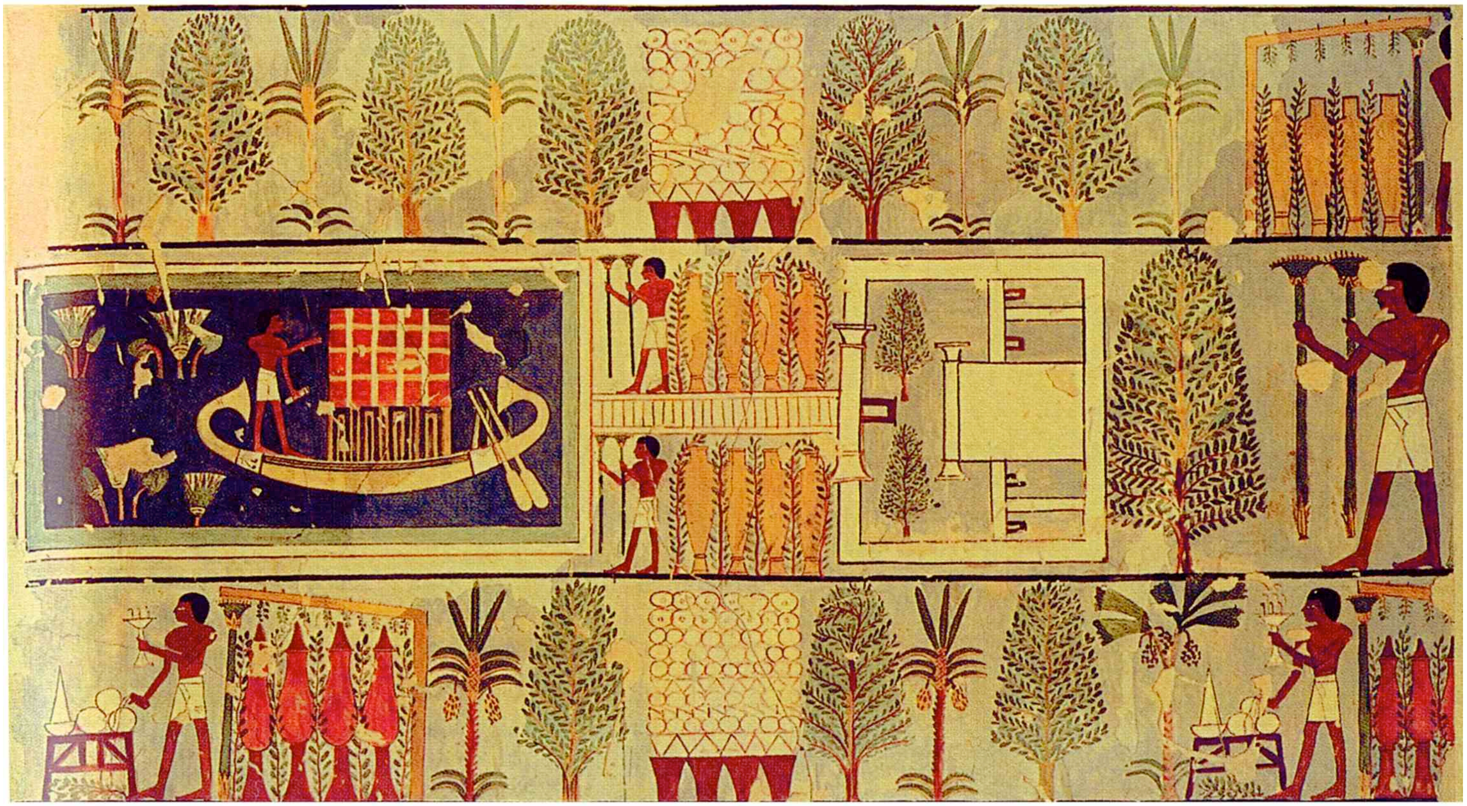
Inventing Agriculture and "Domesticating" Plants and Animals 10,000 Years Ago Changed That & Everything Else!!!

The Invention Of Agriculture Led To Civilization As We Know It!!!



Agriculture Dates Back 10,000 Years

Breeding And Cultivation Of Plants Have Taken Place Over Thousand Of Years



Generating New Types Of Crops Is Not New To The 21st Century!!

Crops of Egypt - 400 BC

All Major Food Crops Were "Engineered" By Breeding ~10,000 Years Ago

- **SEEDS (cereals):** *corn, rice, wheat, barley, millet, sorghum*
- **SEEDS (legumes):** *soybean, beans, peanut*
- **ROOTS AND STEMS:** *potato, cassava, yam, sugar beet, sugar cane, radish*
- **FRUITS:** *tomato, banana, coconut, papaya*
- **LEAVES:** *cabbage, kale, lettuce, spinach*
- **FLOWERS:** *broccoli, cauliflower, artichoke*

Crops were selected by using pre-existing genetic variability in wild plant populations -- They Were Made by "Man" and Not by Nature !!

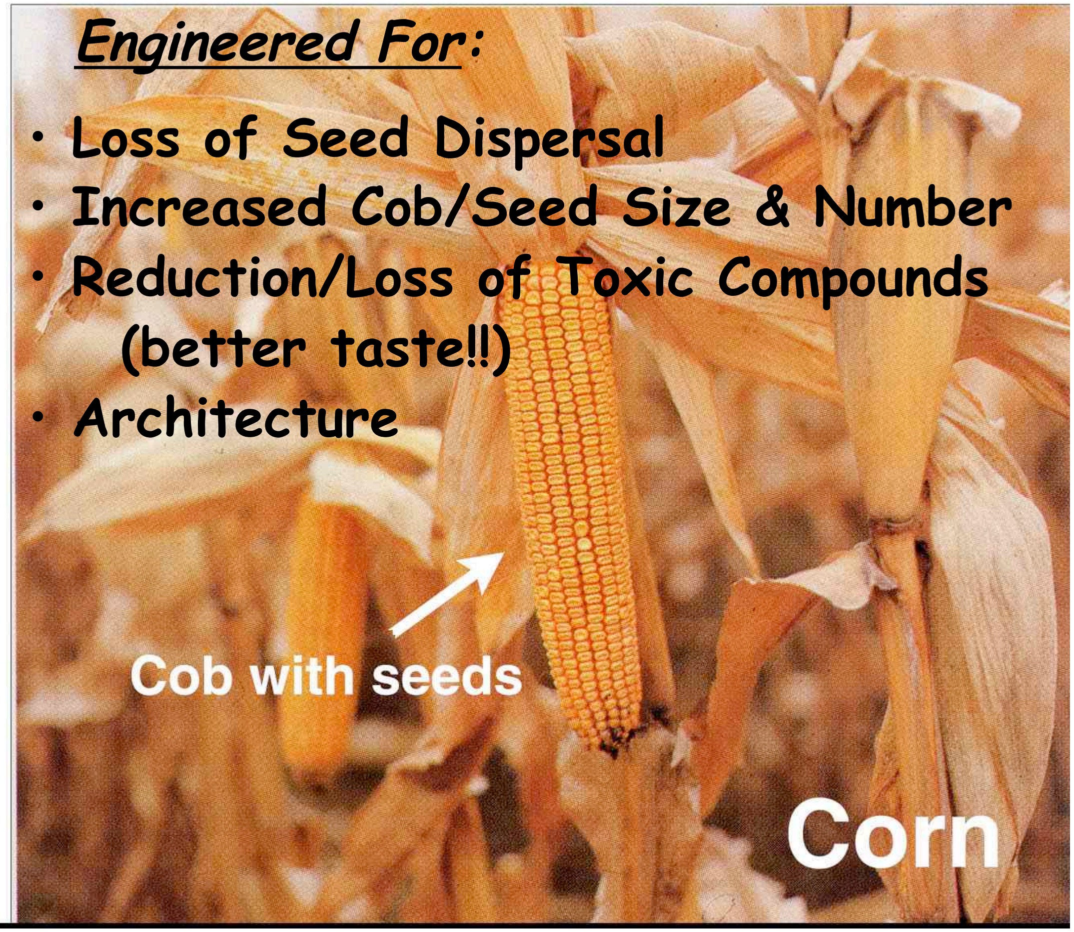
Breeding, By Definition, Means Manipulating Genes!!!!

Engineering Teosinte Into Domesticated Corn

Teosinte | Domesticated corn | Teosinte | Early domesticated corn

<u>Note</u>: Architecture and Fruit (cob) Size

Early Breeders Generated Corn From Teosinte



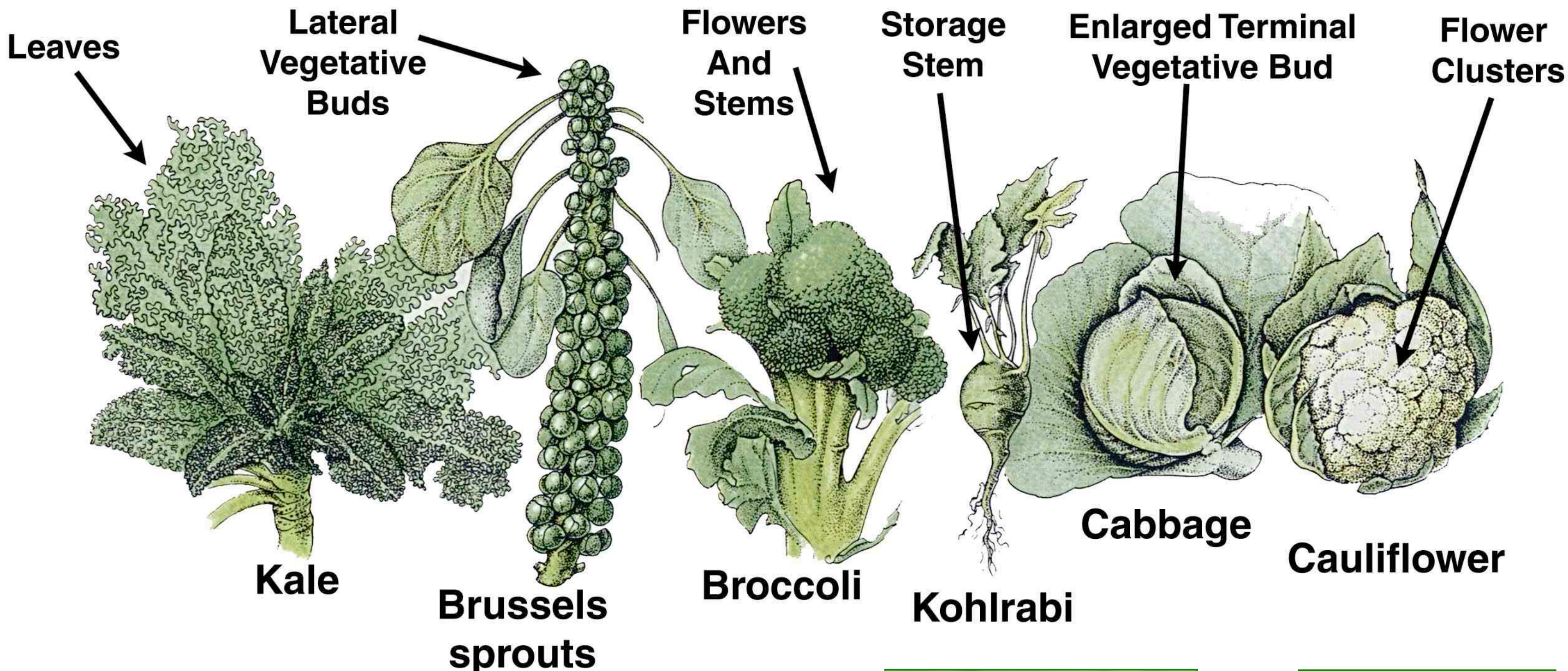
Engineered For:

- Loss of Seed Dispersal
- Increased Cob/Seed Size & Number
- Reduction/Loss of Toxic Compounds (better taste!!)
- Architecture

Modern Corn Was "Engineered" From Teosinte 10,000 Years Ago & Cannot Survive in "Nature!!"

Tomatoes Were Engineered From Small Wild Relatives

Broccoli, Cauliflower, Cabbage, and Brussels Sprouts Were "Engineered" As Well!



…….Brassicas or Crucifers

Big Changes in the US Over The Past 100 Years

"We've Come a Long Way Baby"

	1900	2008
Life Expectancy	48 (women)	79 (women)
Average Family Income (2008 Dollars)	$8,000	$50,000
Gasoline Use Per Capita	34 gallons	1,100 gallons
Flush Toilets Per Housing Unit	10%	99%
High School Grads	13%	90%
Farm Workers	55%	1.5%

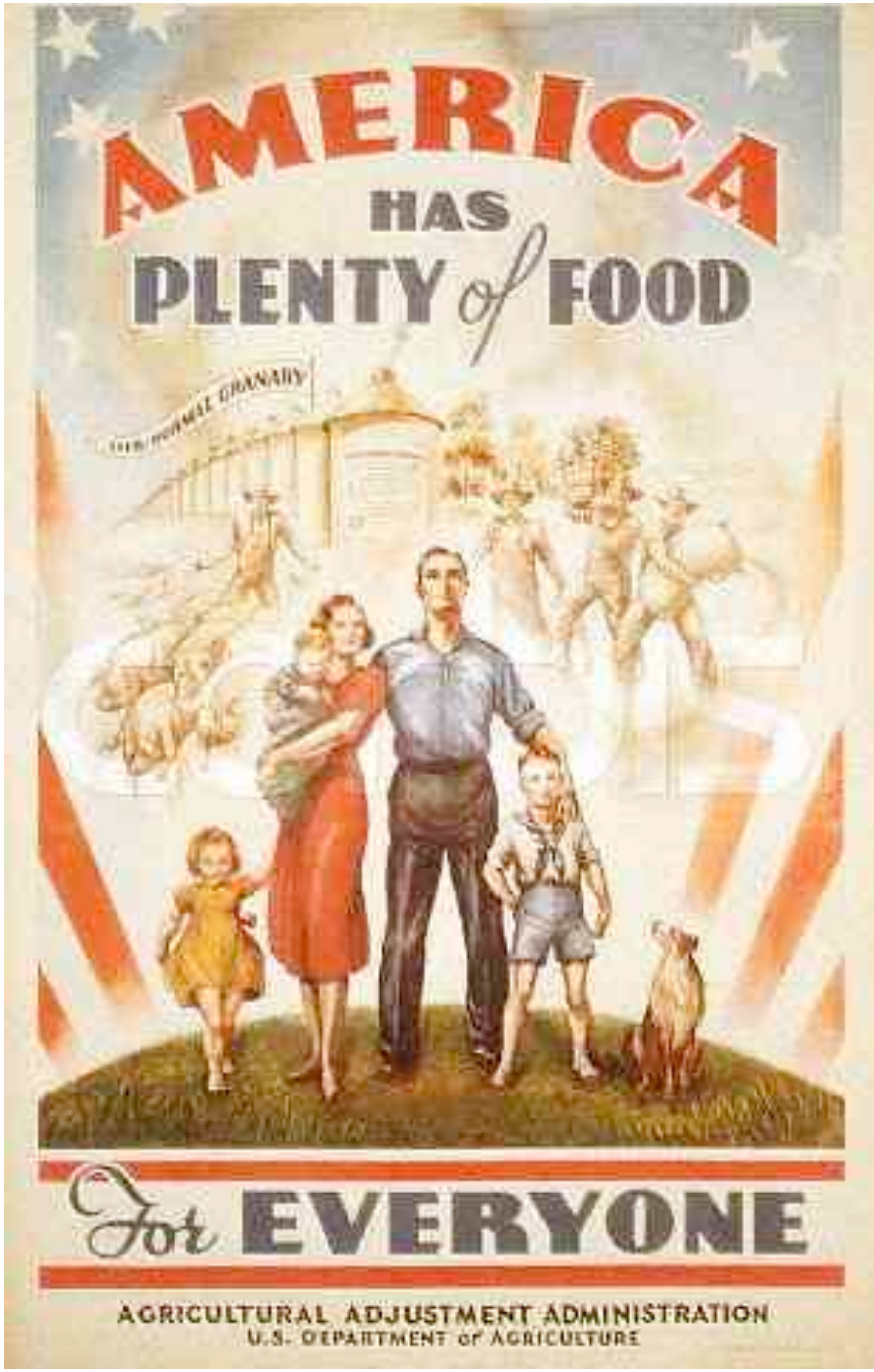
CROP YIELD INCREASES HAVE "ROCKETED UPWARDS" OVER THE LAST 100 YEARS AND CONTRIBUTED TO A LONGER AND "BETTER" LIFE

% Farm Workers	% Income on Food			Life Span
55%	50% →	• 1900	100	← 48 Years
		• 1920	115	
		• 1940	145	
		• 1950	200	
1.5%	9% →	• 2008	300	← 79 Years

1930: 30 bushels/acre
1930: 1 farmer fed 10 people

2008: 150 bushels/acre
2008: 1 farmer feeds 200 people

Conclusion: Crop yield increased ~ 300% over the past 100 years and lead to a similar reduction in food costs!!!!!



How Was This Accomplished Over the Past 100 Years?

What Role Did Science & Technology Play?

What About in the Future When There are 400 Million People in the USA and 9 Billion in the World?

WHAT TECHNOLOGIES CAUSED AN INCREASE IN CROP YIELDS OVER THE PAST 100 YEARS?

- PLANT BREEDING (New Hybrids-Green Revolution)
- IRRIGATION
- FERTILIZERS
- PESTICIDES & HERBICIDES
- MECHANIZATION (e.g., Tractor)
- GLOBAL POSITIONING AND SATELLITE IMAGING
- GENOMICS & GENETIC ENGINEERING (New Traits)

These technologies have resulted in a 300% increase in US crop productivity during the 20th-21st century! Need to sustain this yield increase by applying the best technology and agricultural practices!

Genetics Has Also Changed Dramatically Over the Past 100 Years!!

1900: Rediscovery of Mendel's Work

DeVries, Correns and Tschermak independently rediscover Mendel's work.

Three botanists - Hugo DeVries, Carl Correns and Erich von Tschermak - independently rediscovered Mendel's work in the same year, a generation after Mendel published his papers. They helped expand awareness of the Mendelian laws of inheritance in the scientific world.

The three Europeans, unknown to each other, were working on different plant hybrids when they each worked out the laws of inheritance. When they reviewed the literature before publishing their own results, they were startled to find Mendel's old papers spelling out those laws in detail. Each man announced Mendel's discoveries and his own work as confirmation of them.

1909: The Word Gene Coined

Danish botanist Wilhelm Johannsen coined the word gene to describe the Mendelian units of heredity.

He also made the distinction between the outward appearance of an individual (phenotype) and its genetic traits (genotype).

Four years earlier, William Bateson, an early geneticist and a proponent of Mendel's ideas, had used the word *genetics* in a letter; he felt the need for a new term to describe the study of heredity and inherited variations. But the term didn't start spreading until Wilhelm Johannsen suggested that the Mendelian factors of inheritance be called *genes*.

The proposed word traced from the Greek word *genos*, meaning "birth". The word spawned others, like *genome*.

1911: Fruit Flies Illuminate the Chromosome Theory

Using fruit flies as a model organism, Thomas Hunt Morgan and his group at Columbia University showed that genes, strung on chromosomes, are the units of heredity.

Morgan and his students made many important contributions to genetics. His students, who included such important geneticists as Alfred Sturtevant, Hermann Muller and Calvin Bridges, studied the fruit fly *Drosophila melanogaster*. They showed that chromosomes carry genes, discovered genetic linkage - the fact that genes are arrayed on linear chromosomes - and described chromosome recombination.

In 1933, Morgan received the Nobel Prize in Physiology or Medicine for helping establish the chromosome theory of inheritance.

Early Fly drawing

Portrait of Morgan at Work

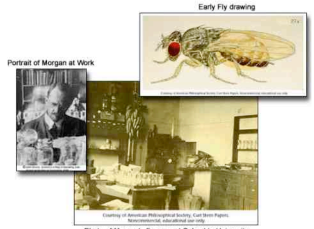
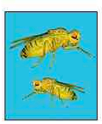


Photo of Morgan's fly room at Columbia University

2000: *Drosophila* and *Arabidopsis* genomes sequenced



Drosophila melanogaster (fruit fly)has been a primary tool for geneticists since the early part of the twentieth century. The sequencing of its genome is the result of a collaborative effort between the *Drosophila* Genome Project Group, led by Gerald Fink at the University of California, Berkeley and researchers from Celera Genomics Corporation led by Craig Venter. The *Drosophila* genome is estimated to have approximately 13,600 genes as compared to 20,000—25,000 genes in humans. The popularity of *Drosophila* as an experimental organism ensures that its genome sequence will be a valuable resource for research in genetics and medicine. Many genes of *Drosophila* have been conserved through evolution and have human counterparts. This means that scientists can perform experiments using flies and apply their findings to human biology.

Arabidopsis thaliana is the first plant to have its genome sequenced. This plant from the mustard family has become the plant biologists' equivalent of the laboratory mouse. Its genome was completed by the collective efforts of an international group of researchers called the *Arabidopsis* Genome Initiative. The *Arabidopsis* genome has an estimated 25,000 genes—apparently even more than humans. Although not a crop plant, *Arabidopsis* was chosen as a model organism because its genome is small and it has relatively little of the noncoding, so-called junk, DNA. It does, however, share very similar biochemistry to crop plants such as rice or barely. The study of its sequence is expected to have widespread applications for agriculture and medicine.

2004: Refined Analysis of Complete Human Genome Sequence

The International Human Gene Sequencing Consortium led in the United States by the National Human Genome Research Institute and the Department of Energy published a description of the finished human gene sequence. The analysis reduced the estimated number of genes (which as recently as the mid-1990's had been ~100,000) from 35,000 to only 20,000-25,000. The fact that the human genome has far fewer genes than was originally thought suggests that humans "get more" out of their genetic information than do other animals. For example, the average human gene is able to produce three different gene products.

The finished sequence contains 2.85 billion nucleotides interrupted by only 341 gaps. It covers 99 percent of the genome with an accuracy of 1 error per 100,000 bases. Researchers confirmed the existence of 19,599 protein-coding genes and identified 2,188 other DNA segments that are thought to be protein-coding genes. Although the genome sequence is described as "finished," it isn't perfect. The small gaps that remain cannot be sequenced by the industrial-scale methods used by the Human Genome Project. Filling in these gaps will have to await a series of small targeted efforts by researchers using other techniques and possibly new technologies. The finished genome sequence can be freely accessed through public databases and may be used by researchers without restrictions.

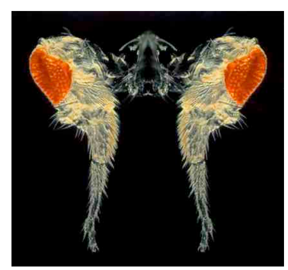
Modern Genetic Engineering Has Come a Long Way Since Its Origins in 1973!

Gene Transplants Seen Helping Farmers and Doctors;

By VICTOR K. McELHENY
May 20, 1974, Monday
Page 61, 1335 words

NY Times-1974

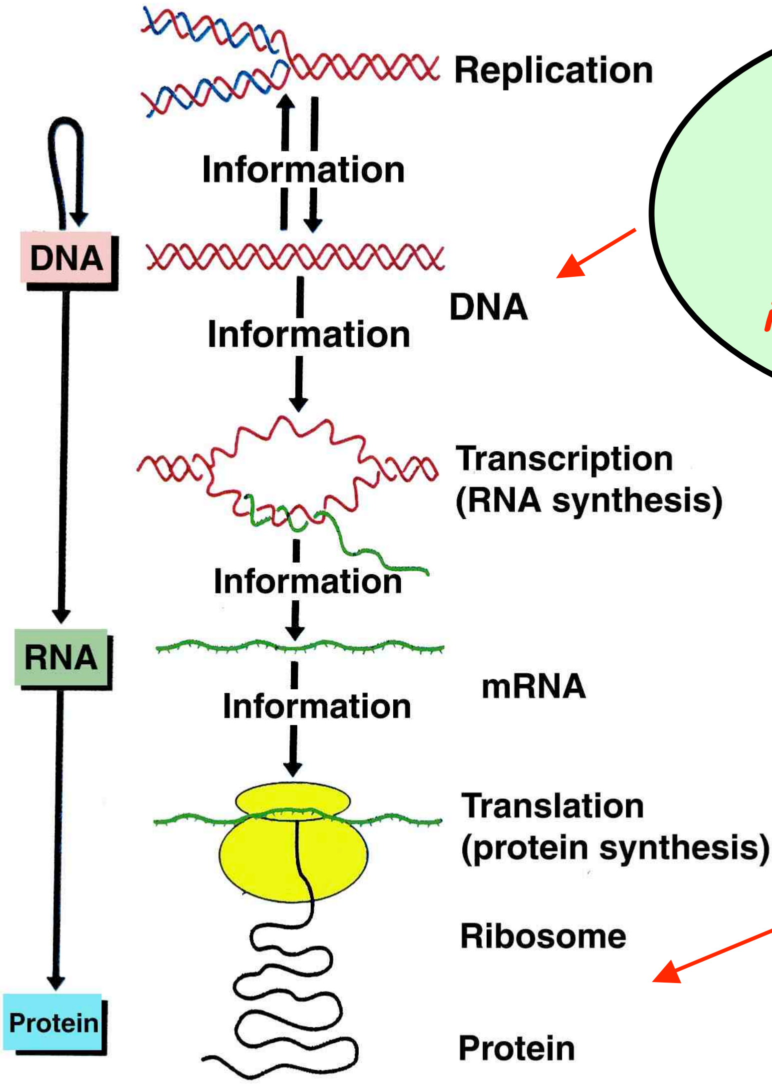
Biochemists working in California have developed a practical method of transplanting genes, the chemical units of heredity, from cells as complex as those of animals into the extremely simple, fast-multiplying cells known as bacteria. [END OF FIRST PARAGRAPH]



Genetic Engineering

Translating The Genetic Code Into Proteins is a Conserved Process

A Natural Process!!



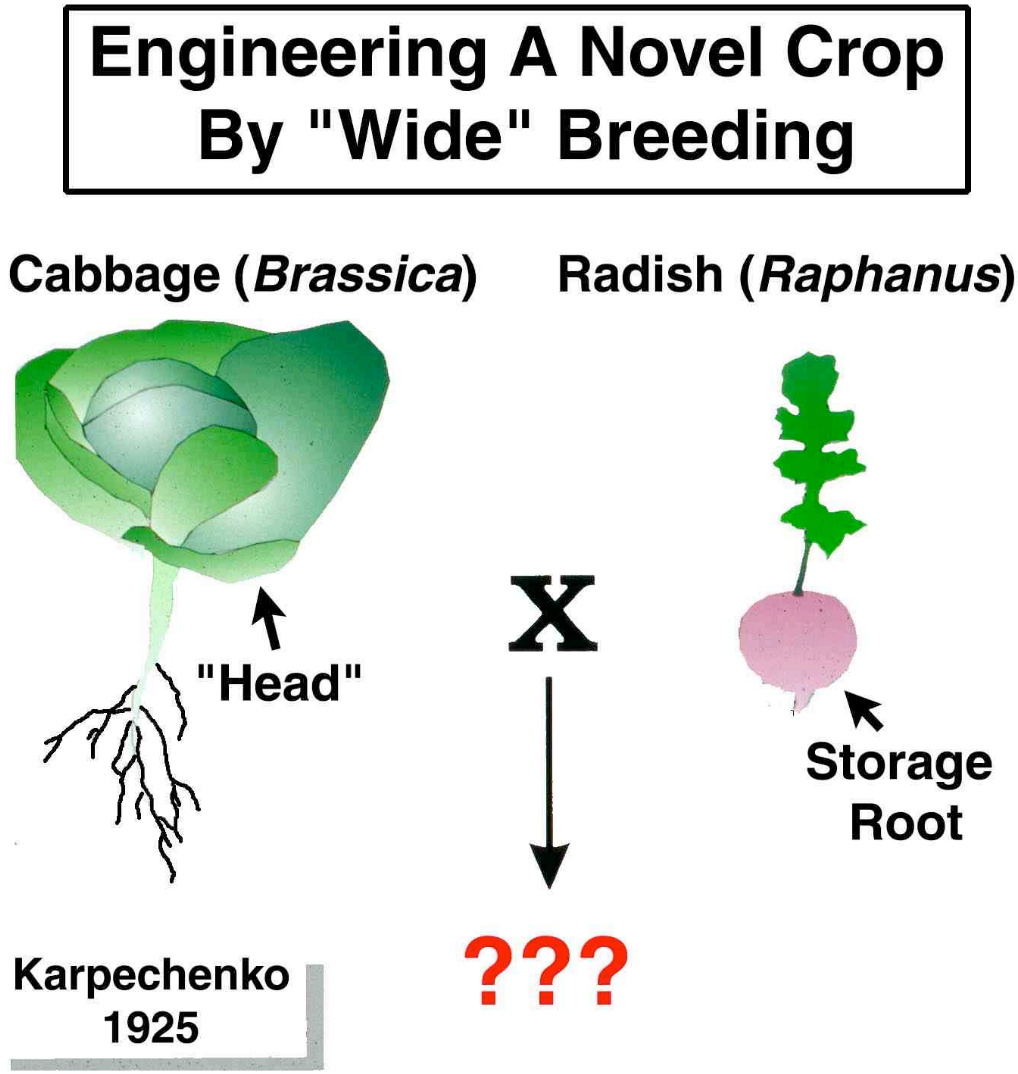
DNA is
DNA is
DNA!!!!
And is the "Same"
in Plants and Humans

Unity in
Biology

Insulin, TPA,
Growth Hormone,
Other Drugs For
Human Health in
Bacterial
Factories!!

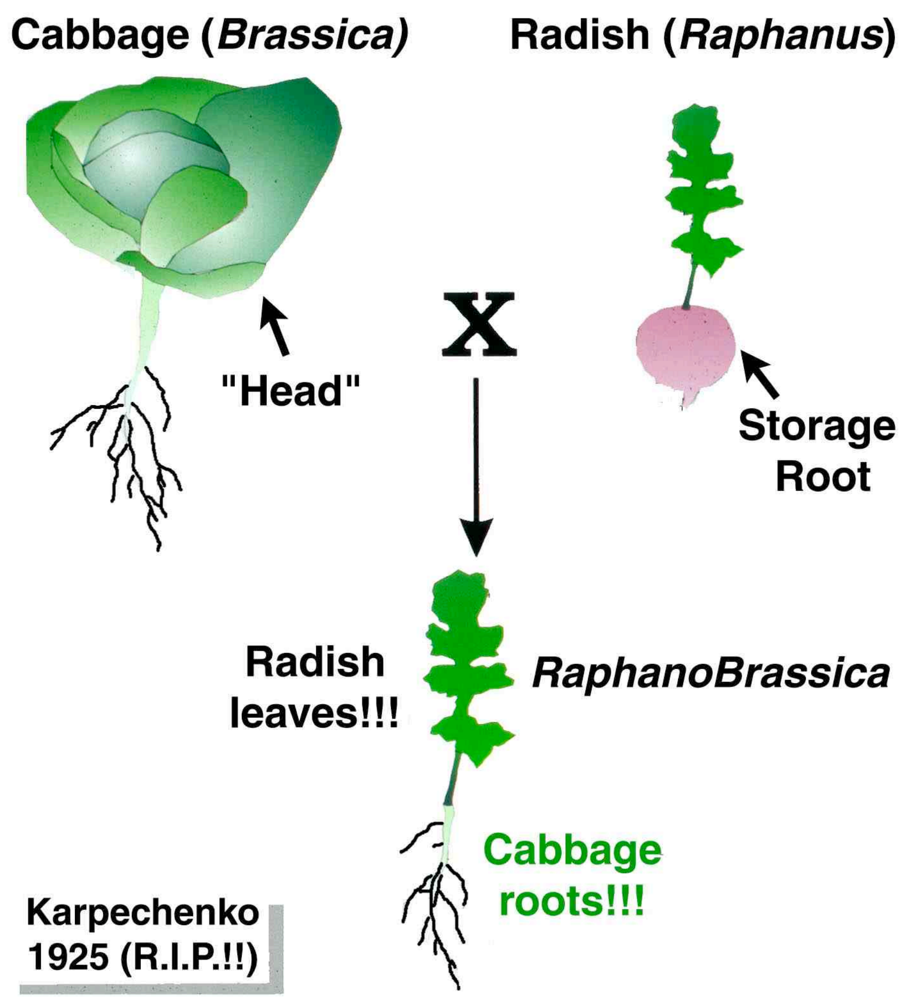
Has Lead to Genetic
Engineering &
Biotechnology

So Has Genetic Engineering in Plants…..



Karpechenko, G.D., 1927. The production of polyploid gametes in hybrids. Hereditas 9, 349–368.

With Unpredictable Results in the Beginning…



Modern Plant Genetic Engineering is Less Than 30 Years Old!

The New York Times
nytimes.com

June 30, 1981

Protein Gene Is Transplanted From Bean to Sunflower

1981

UPI

The New York Times
nytimes.com

August 29, 1986

GENE-ALTERED PLANT TO GET TEST

AP

1986

The crop will consist of only 20 plants, but experts say the tiny tobacco stand may lead to an inexpensive genetic way to fight costly plant-devastating insects.

The Rohm & Haas Company of Philadelphia, one of the world's largest producers of chemicals, announced Wednesday that the United States Department of Agriculture had approved the world's first field test of genetically alterted caterpillar-resistant plants. The Agriculture Department confirmed that the approval had been granted.

Two other chemical companies, Ciba-Geigy and Agracetus, have been conducting similar tests with genetically altered plants resistant to weeds.

The New York Times
nytimes.com

September 3, 1987

COMPANY NEWS; Insect-Resistant Plant Reported

REUTERS

LEAD: A Belgian company said it had made an important scientific breakthrough by altering plants genetically so they became poisonous to insects. Plant Genetic Systems of Ghent said its technique could result in a big reduction in the spraying of farm crops with insecticides.

A Belgian company said it had made an important scientific breakthrough by altering plants genetically so they became poisonous to insects. Plant Genetic Systems of Ghent said its technique could result in a big reduction in the spraying of farm crops with insecticides.

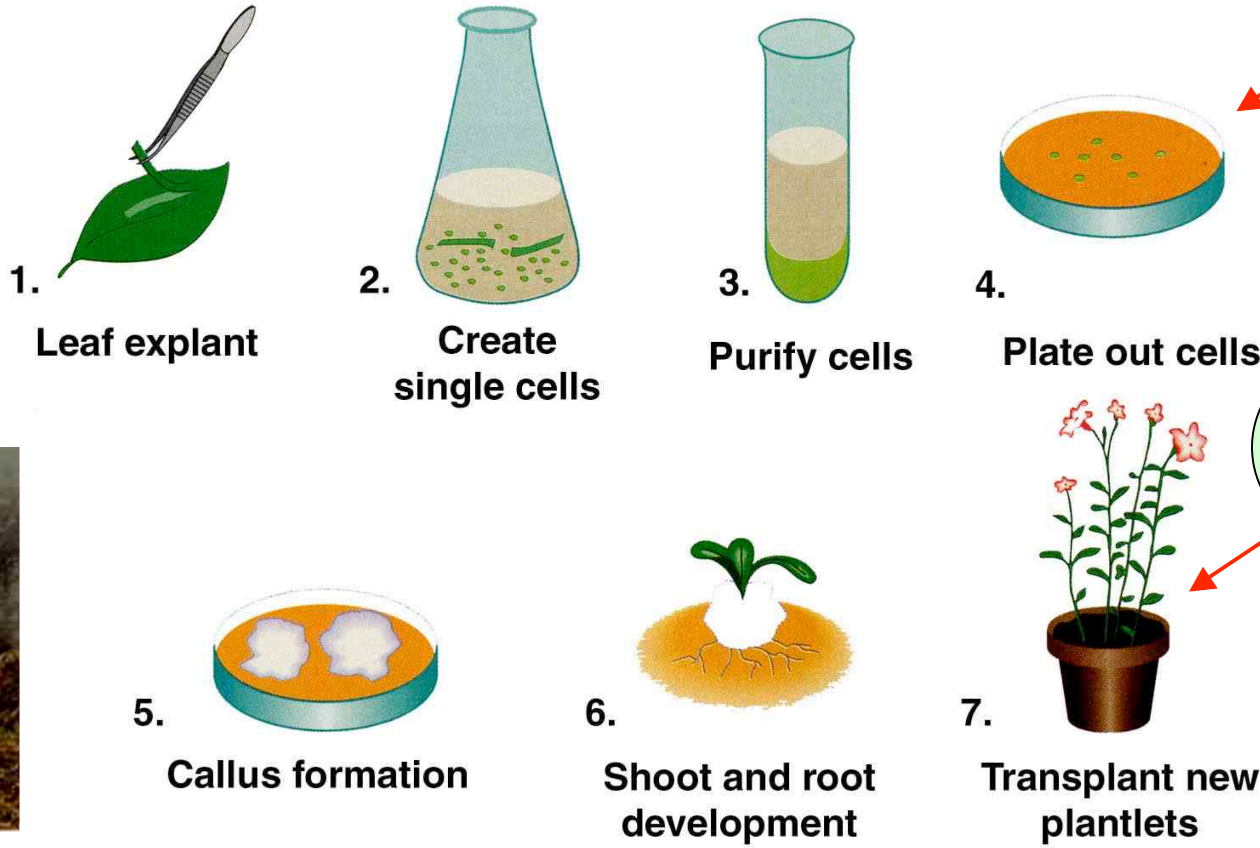
1987

P.G.S. said field trials of tobacco plants altered with the gene of a natural, nontoxic insecticide showed that successive generations of the plants produced enough of the insecticide in their leaves to kill caterpillars.

Plants Can Be Regenerated From Cells in Culture

Engineering Crops.....

Add New Gene



Engineered Crop

Plants ⟶ Cells ⟶ Fertile Plants

Before There Was Dolly the Sheep There Were Cloned Orange Carrots!!!!

Plant Genome Projects Are Identifying Genes Essential For Increasing Crop Yields!!

Plant Genomes Sequenced To Date

- Arabidopsis
- Rice
- Poplar Tree

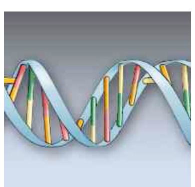
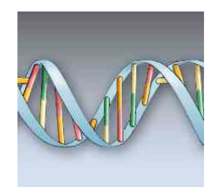


- Soybean
- Corn
- Medicago

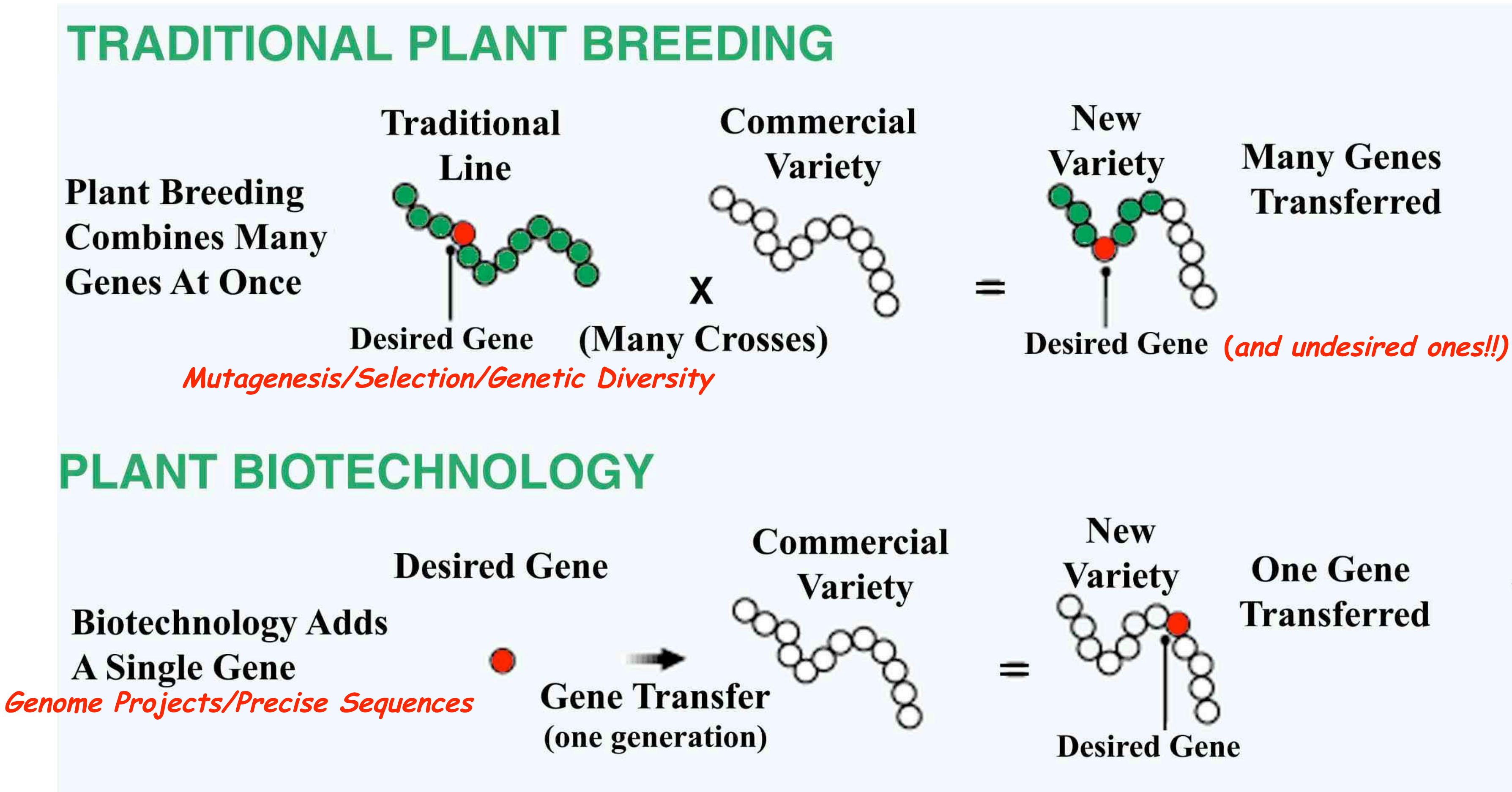


- Papaya
- Grape
- Castor Bean

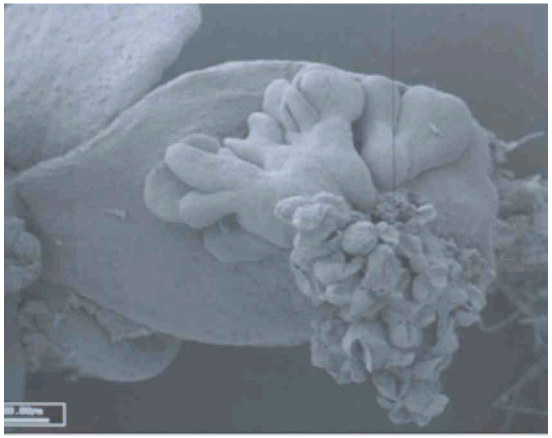


Gene Engineering Techniques Can Also Be Used To Transfer Specific Genes Into Crops

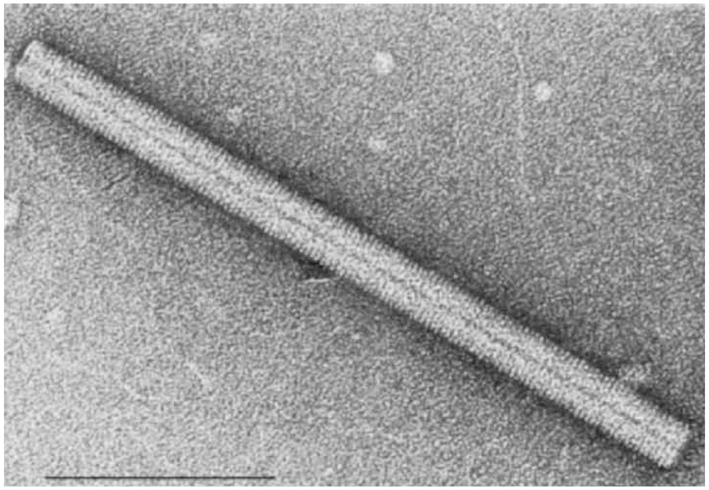


__Conclusion__: Plant Genome Projects & Genomics Allow Us to Identify Genes That Can Be Used to Improve Crops Plants Using __Classical & Genetic Engineering Approaches__



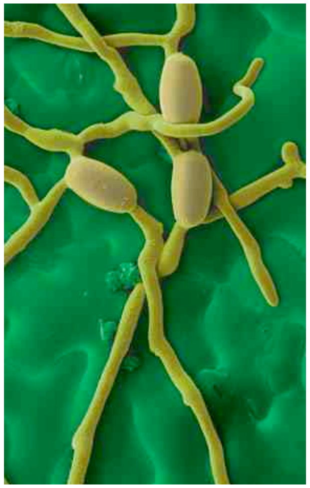
Genetic Engineering Has the Advantage of Allowing Everything That's Possible Biologically To Be Achieved

We Are Only Limited By Our Imagination and Knowledge of Biological Processes



Specific Examples of Bioengineered Crops

Pest Resistance



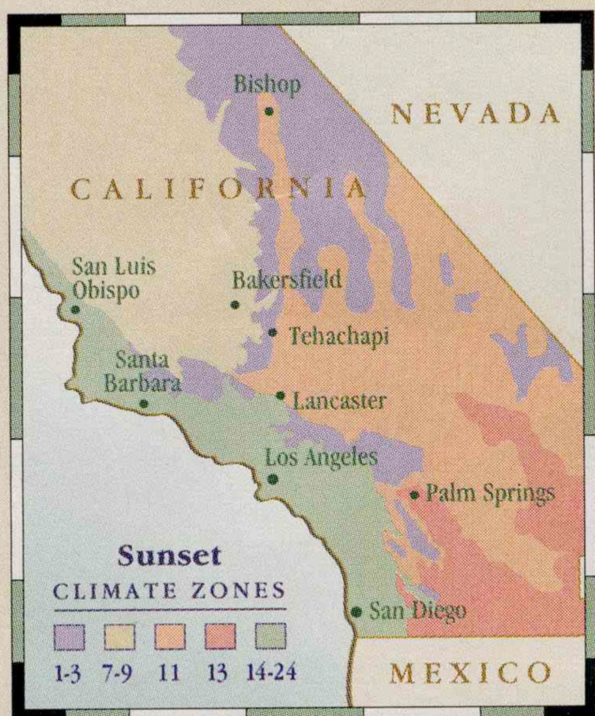
How to Control Insects?

GARDEN | GUIDE

SUNSET

WHAT TO DO IN YOUR GARDEN IN SEPTEMBER

Southern California Checklist

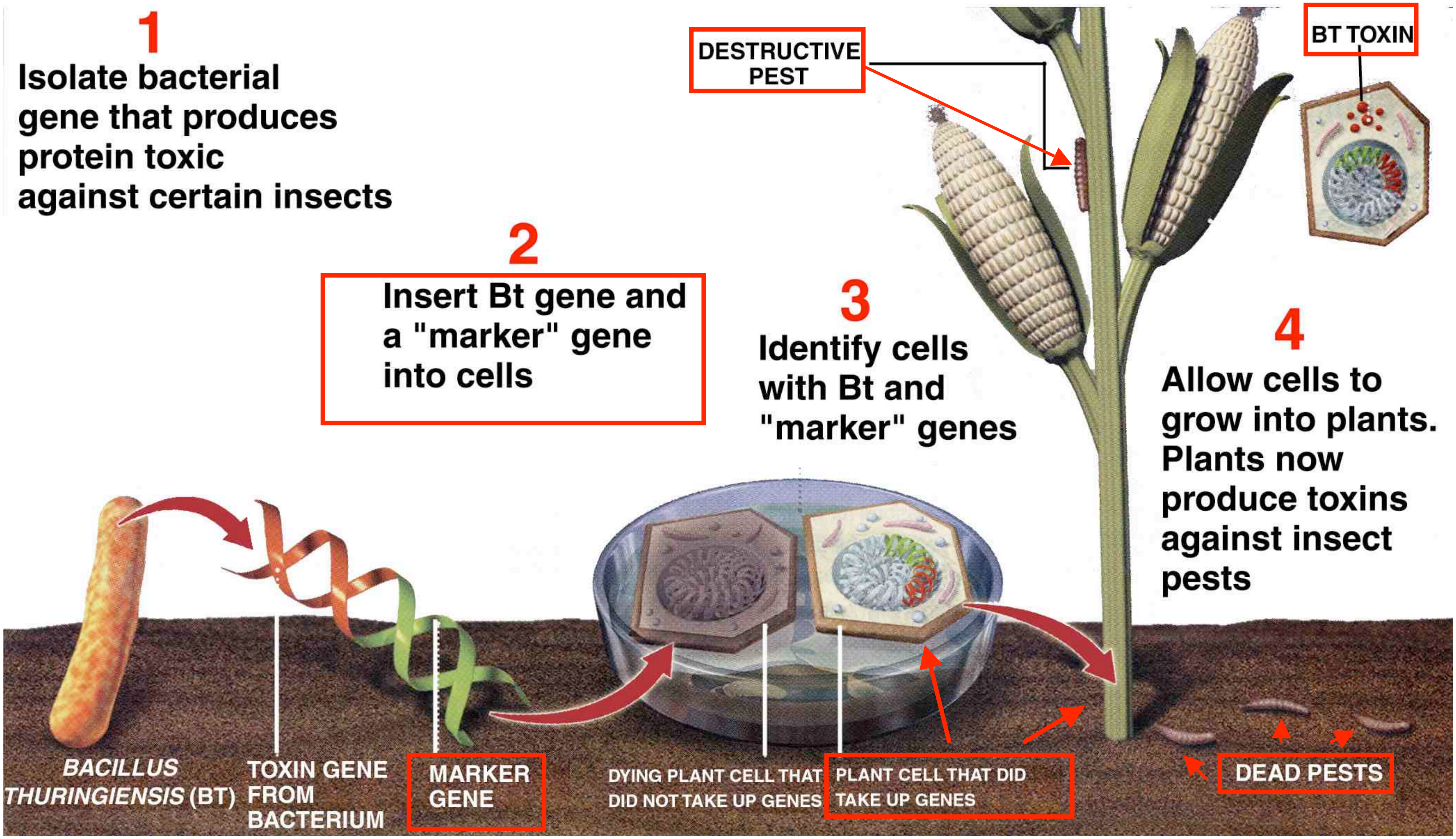


DEBRA LAMBERT

✔ **PROTECT CABBAGE CROPS.** The minute you plant a brassica, squadrons of cabbage white butterflies seem to descend on it to lay their eggs. The easiest way to thwart them is to cover your cabbage crops with row covers right from the start. The next best option is spraying with *Bacillus thuringiensis* to kill the young caterpillar larvae. ◆

Bt Has Been Used For Many Years To Control Pests by Conventional And Organic Farmers !!!

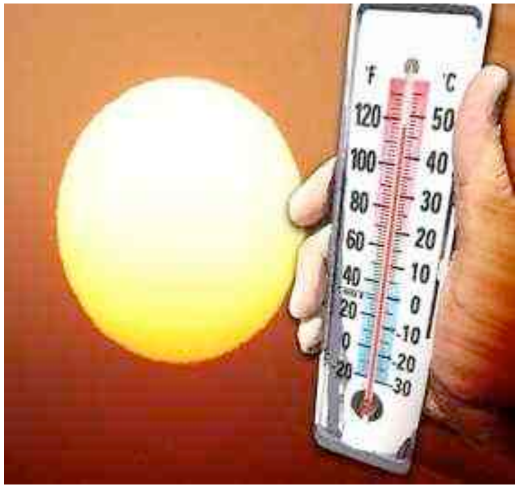
How to Make an Insect-Resistant Plant



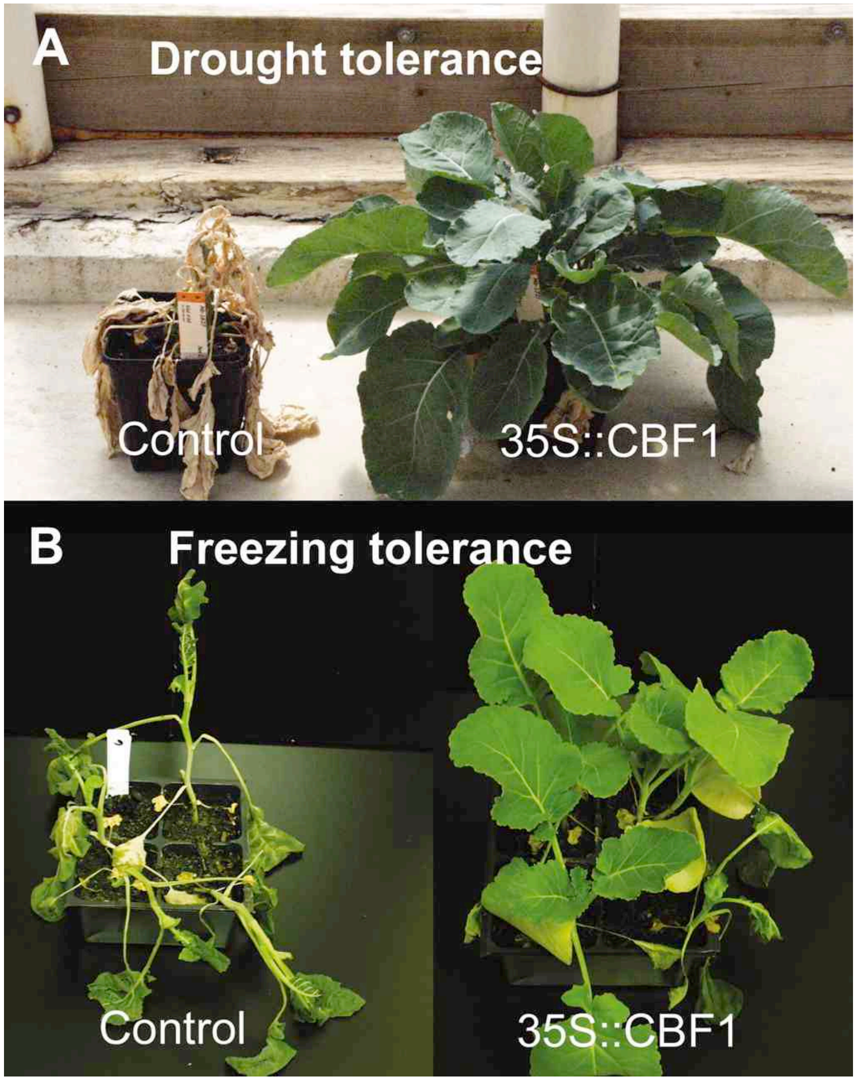

INSECT
RESISTANCE
with Bt
CONTROL
Bt

Specific Examples of Bioengineered Crops

Abiotic Stress



Identifying Genes For Drought and Freezing Tolerance
Major Factors in Lowering Crop Yield



Zhang et al. Plant Physiology 135, 615-621 (2004)

Using a <u>Wild Potato Gene</u> to Engineer Potato Plants Resistant to Potato Blight Fungus

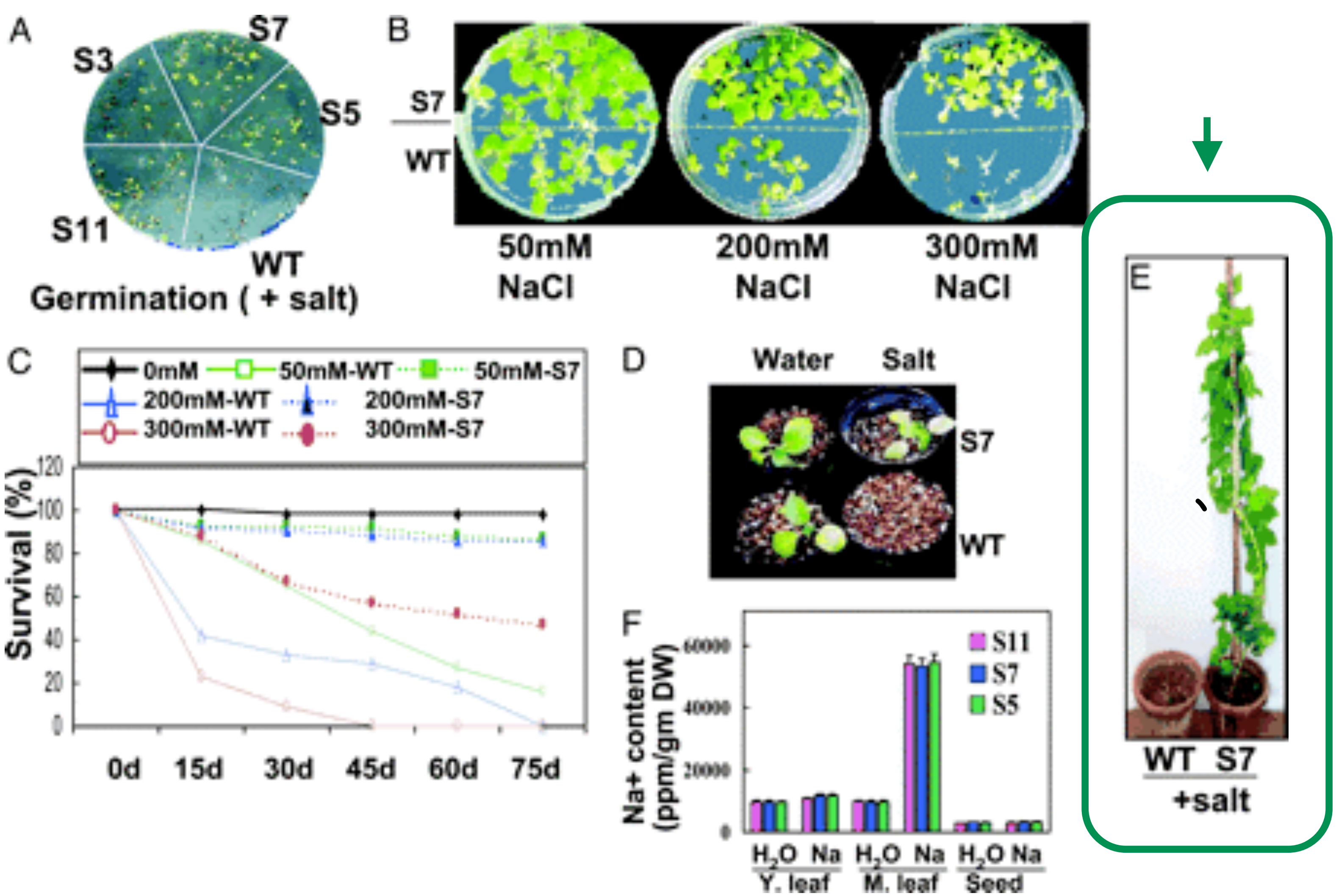
Resistant Transgenic Plant

Sensitive Non-Transgenic Control

Potato Blight Caused the Irish Famine That Killed One Million People in the Late 19th Century and Resulted in a Large Migration of Irish People to the United States!!!

"Gene RB Cloned From Solanum bulbocastanum Confers Broad Spectrum Resistance to Potato Late Blight" Song et al., PNAS 100, 9128-9133 (2003)

Identifying Salt Tolerant Genes

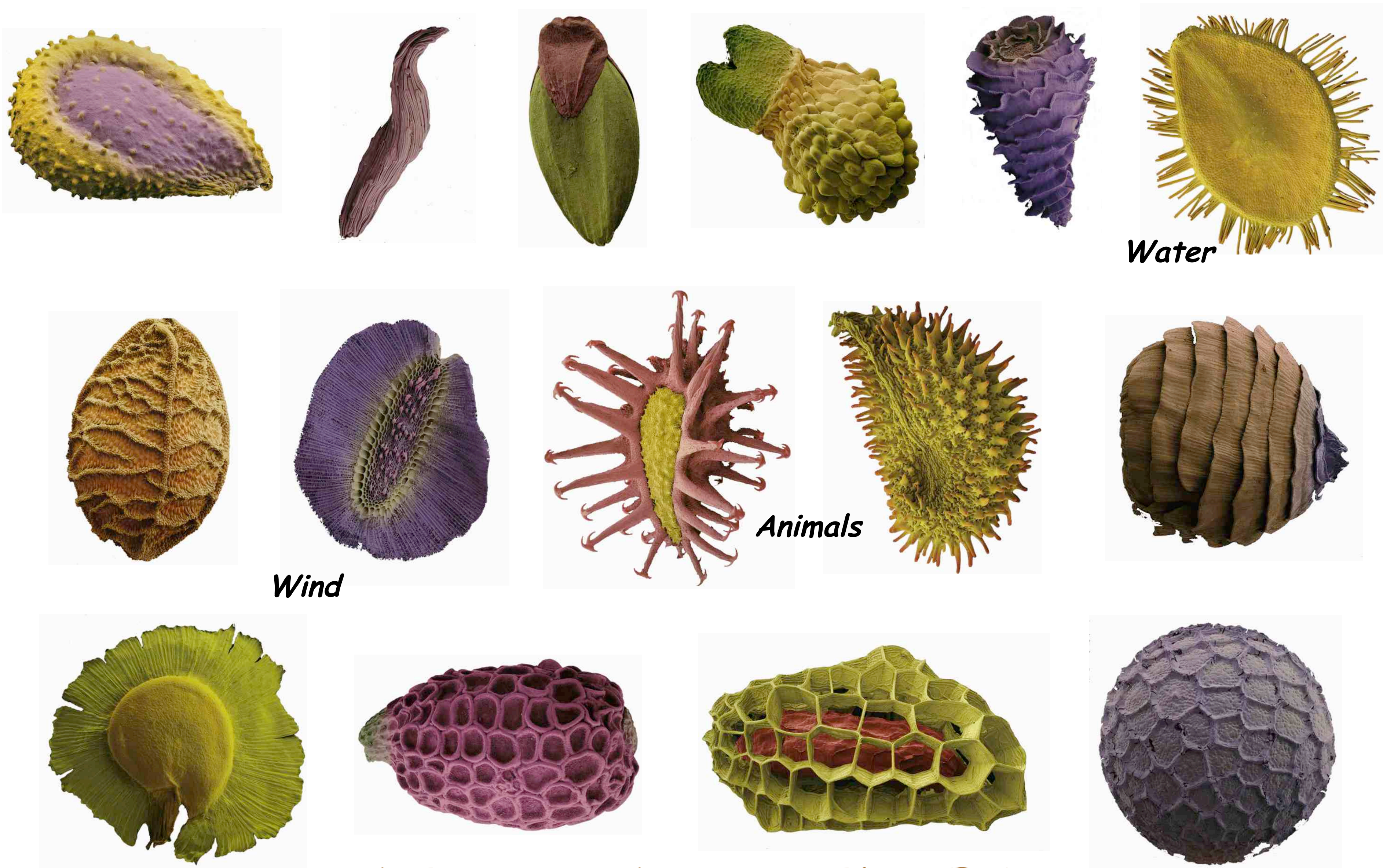


Sanan-Mishra et al. PNAS 102, 509-514 (2005)


Specific Examples of Bioengineered Crops

Seeds


So……Why Seeds??



Seeds Protect and Disperse Plant Embryos and Come in Many Shapes and Sizes!

Seeds Are Used in Many Ways as Food, Beverages, Spices, and Fuels!

Beans

Peas

Wheat

Corn

Coconut

Cashew Nuts

Peanuts

Pecans

Cocoa Beans

Coffee Beans

Nutmeg

Mustard

Most Importantly….. Our Food is Derived From Fourteen Crops & Over Half Produce Seeds For Human and Animal Consumption

Seed Crops

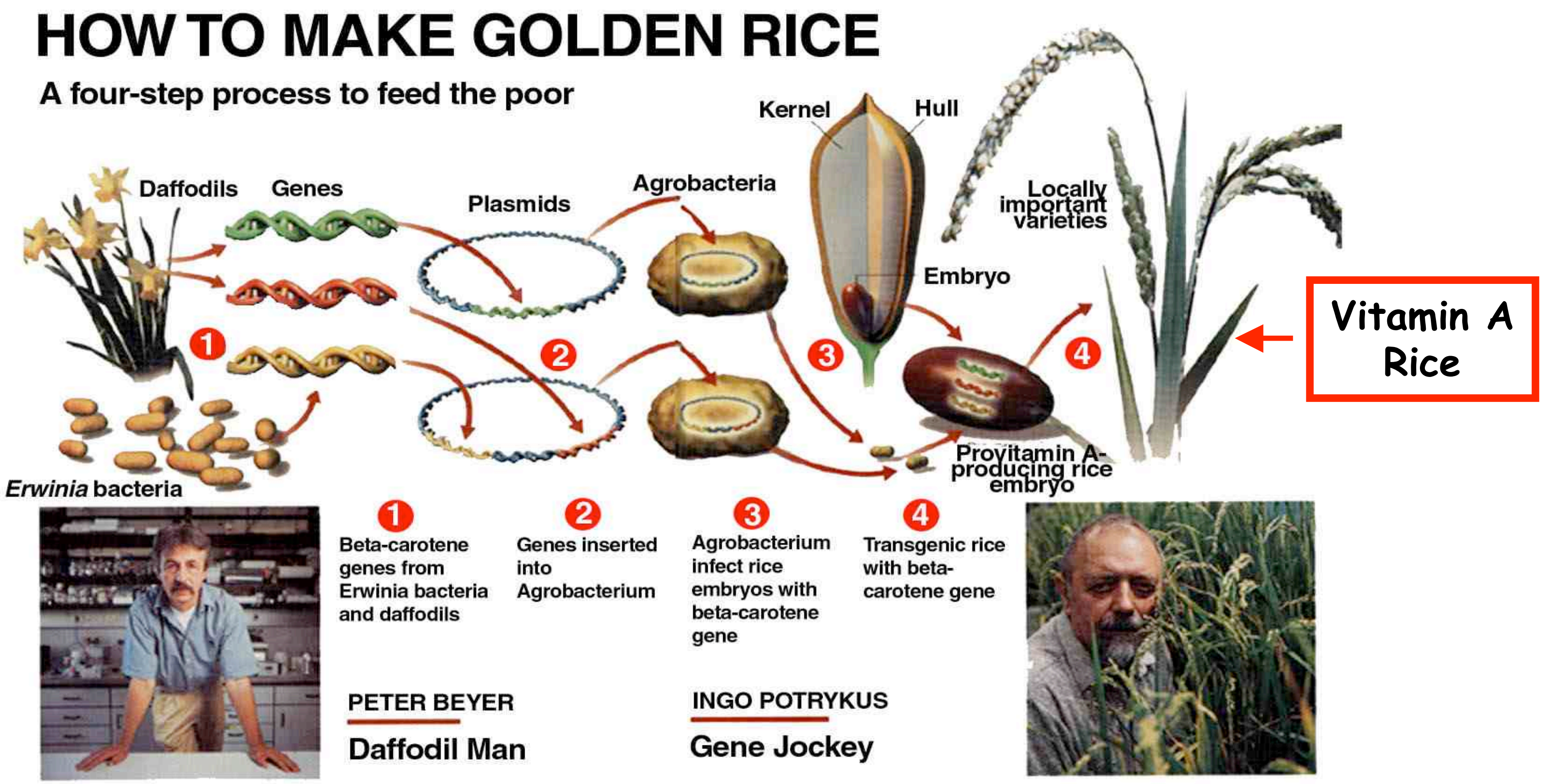
- Wheat
- Rice
- Corn
- Barley
- Sorghum
- Soybean
- Common Bean
- Coconut

Non-Seed Crops

- Potato
- Sweet Potato
- Cassava
- Sugar Beet
- Sugar Cane
- Banana

In Some World Populations 75% of Calories Are Derived From Seeds!

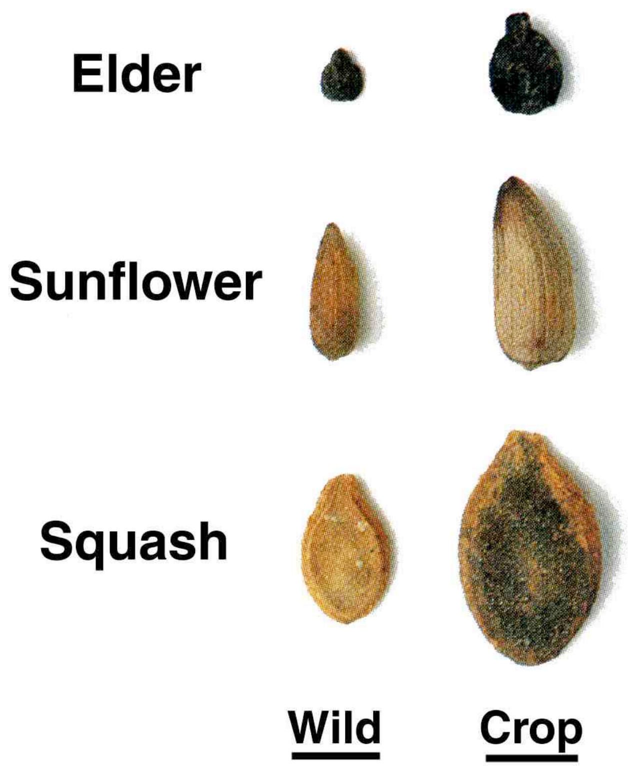
Vitamin A Deficiency Causes 1,000,000 Deaths Per Year!



Nutritionally-Enhanced Rice Seeds

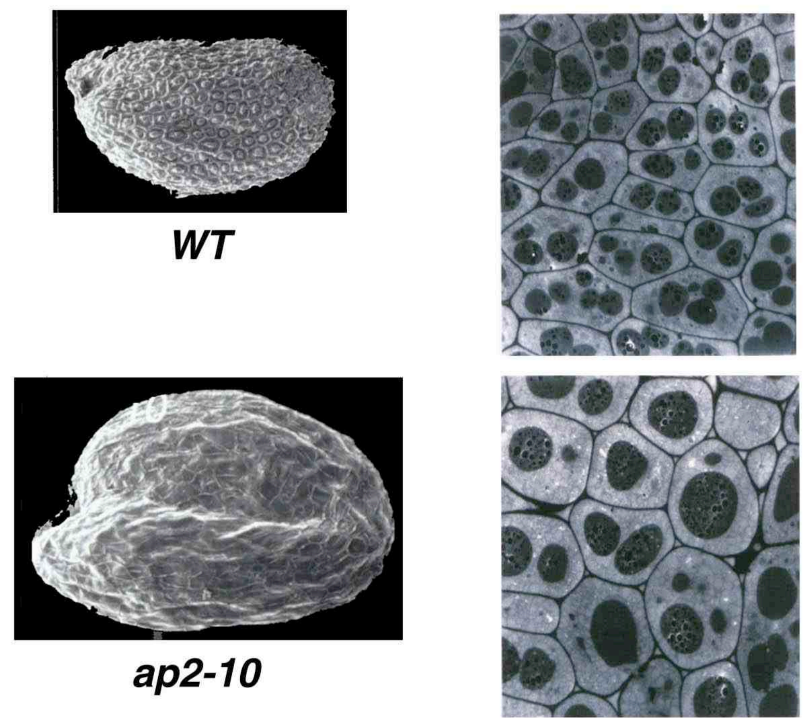
Engineering For Seed Size & Yield Is Not New!

Engineering Bigger Seeds 10,000 Years Ago



Our American Ancestors, 10,000 BC

Engineering Bigger Seeds Today

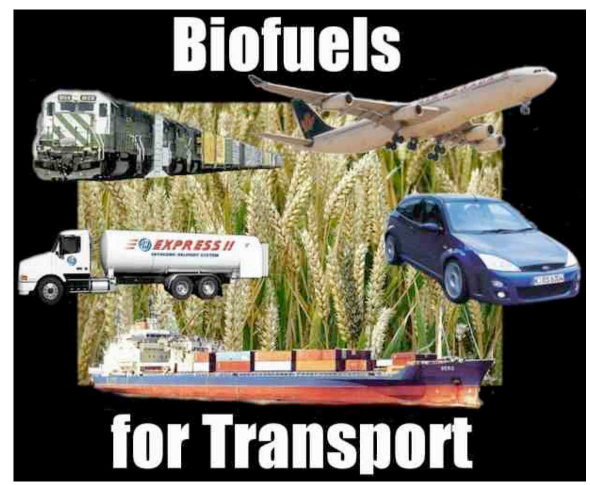


But Need to Identify the Critical Genes

Jofuku et al., PNAS, 2005

Specific Examples of Bioengineered Crops

Biofuels

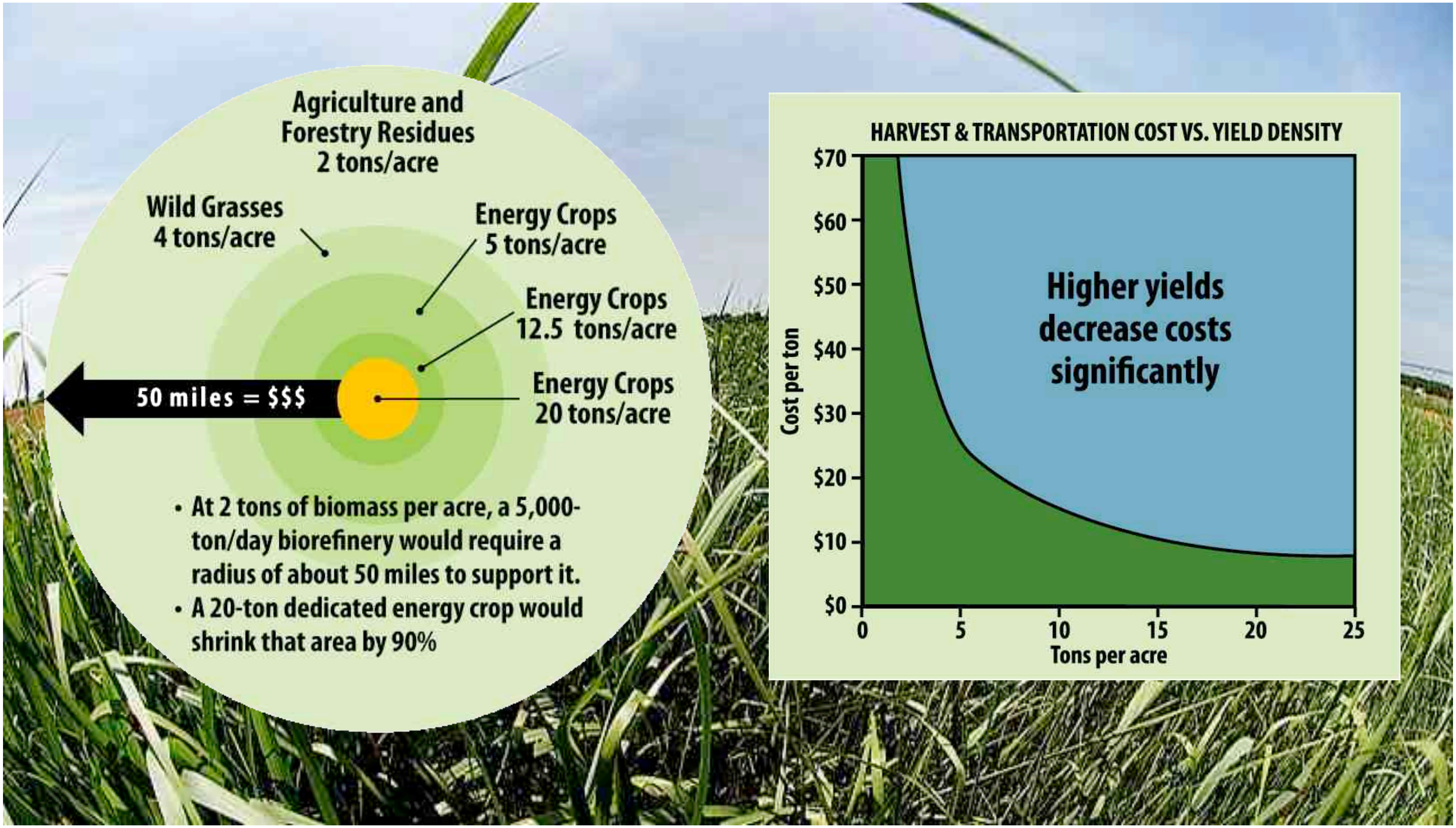


Using Dedicated Energy Crops To Produce Biofuel

"*With plausible technology developments*, **biofuels could supply some** *30% of global demand* **in an environmentally responsible manner without affecting food production. To realize that goal, so-called advanced biofuels must be developed from** *dedicated energy crops*, **separately and distinctly from food."**

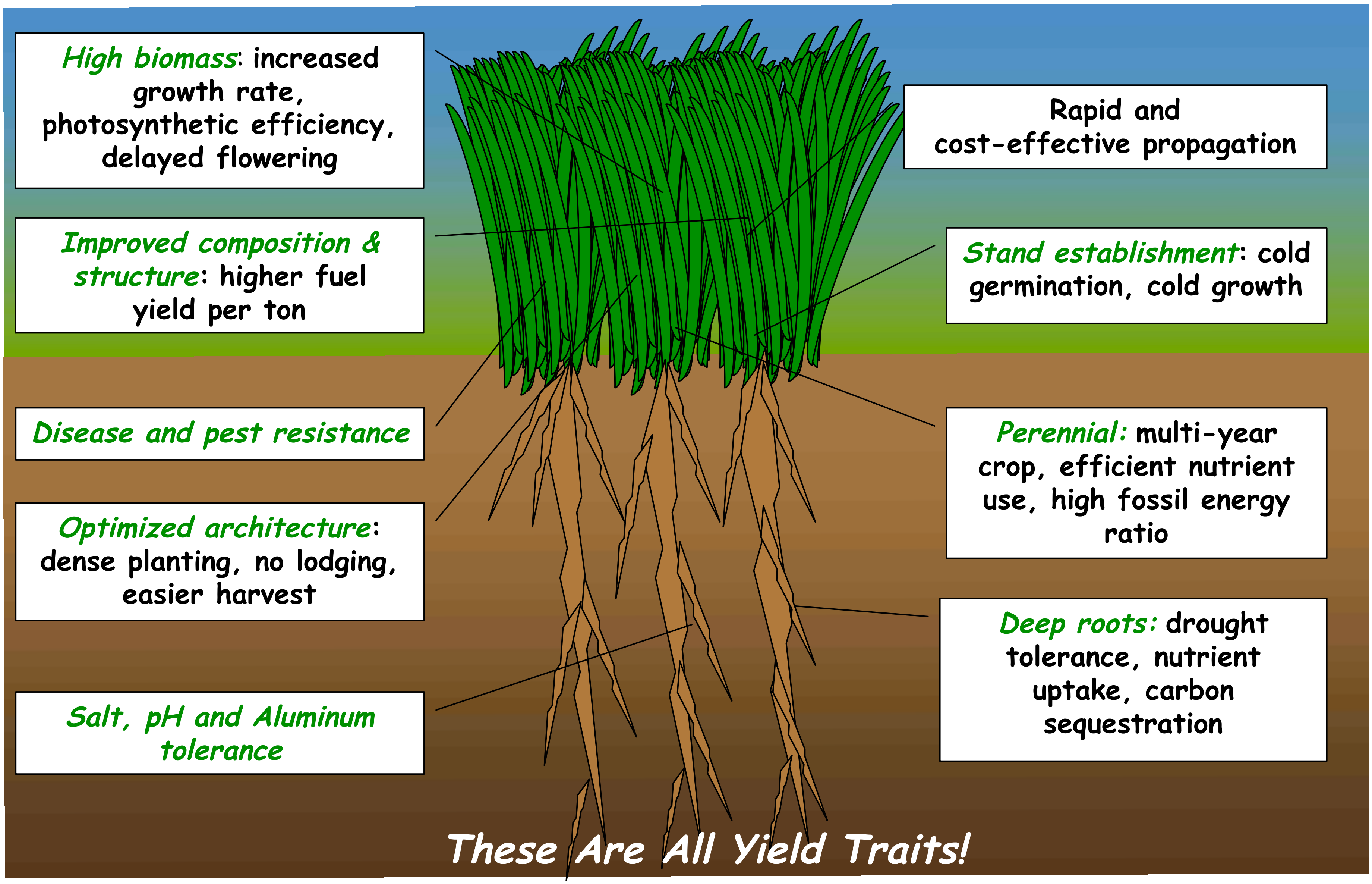
Steven E. Koonin
Chief Scientist, British Petroleum

Biomass Yield Matters



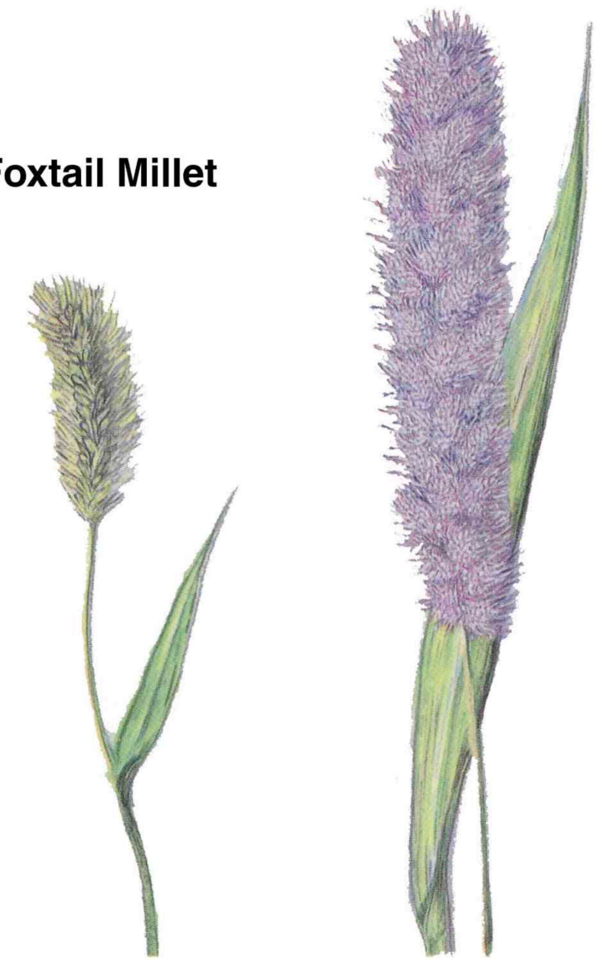
Potential Dedicated Energy Crops

The "Perfect" Energy Crop



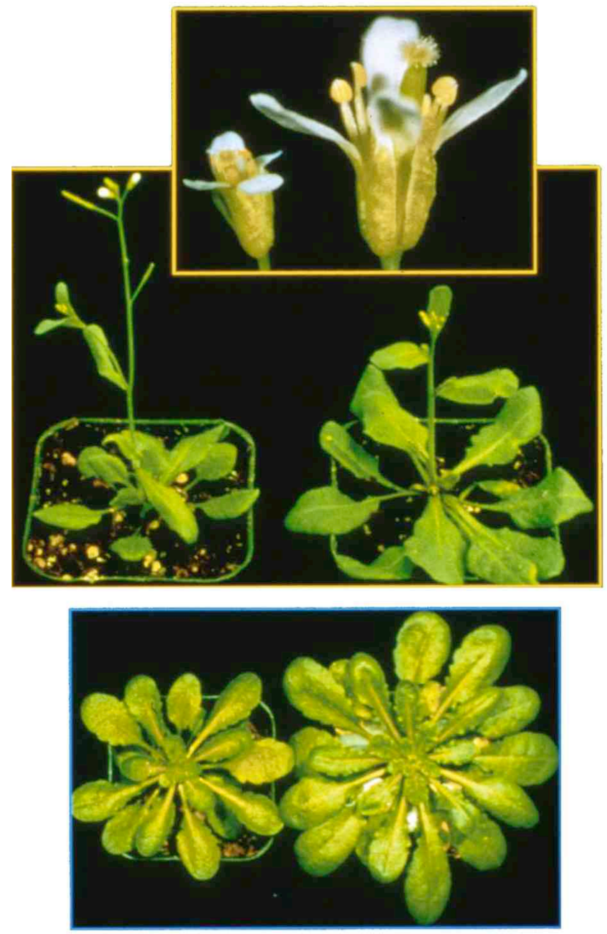
Engineering Biomass
10,000 Years Ago

Foxtail Millet



Wild Domesticated

Engineering Biomass
2008



35S:ANT

Bob Fischer
UC Berkeley

Plants Have Been Engineered For Large Numbers of Traits in Laboratories Around the World

Tens of Thousands of GE Experiments!!

Genetically Engineered Traits

Improving Pest and Weed Management

- Herbicide tolerance
- Virus resistance
- Insect resistance
- Bacterial resistance
- Fungal resistance

**Chemical Free* Crops*

Improving Agronomic Properties

- Altering cold sensitivity
- Improving water stress tolerance
- Improving salt tolerance
- Improving nutrient uptake
- Drought Resistance*

Crops in Desert & Drought

Improving PostHarvest Qualities

- Delay of fruit ripening
- Delay of flower senescence/timing
- High-solids tomatoes
- High-starch potatoes
- Sweeter vegetables

Longer Lasting Crops

Improving Plant Breeding

- Male sterility; production of hybrid seeds

Improving Nutritional Quality

- High-methionine and high-lysine seeds
- Decaffeinated Coffee*
- Vitamin-enriched grains
- Allergen-free seeds/grains*

**Healthier* Crops*

Molecular Farming

- Oils
- Starch
- Plastic
- Enzymes, Pharmaceuticals
- Ethanol/Transportation Fuel*

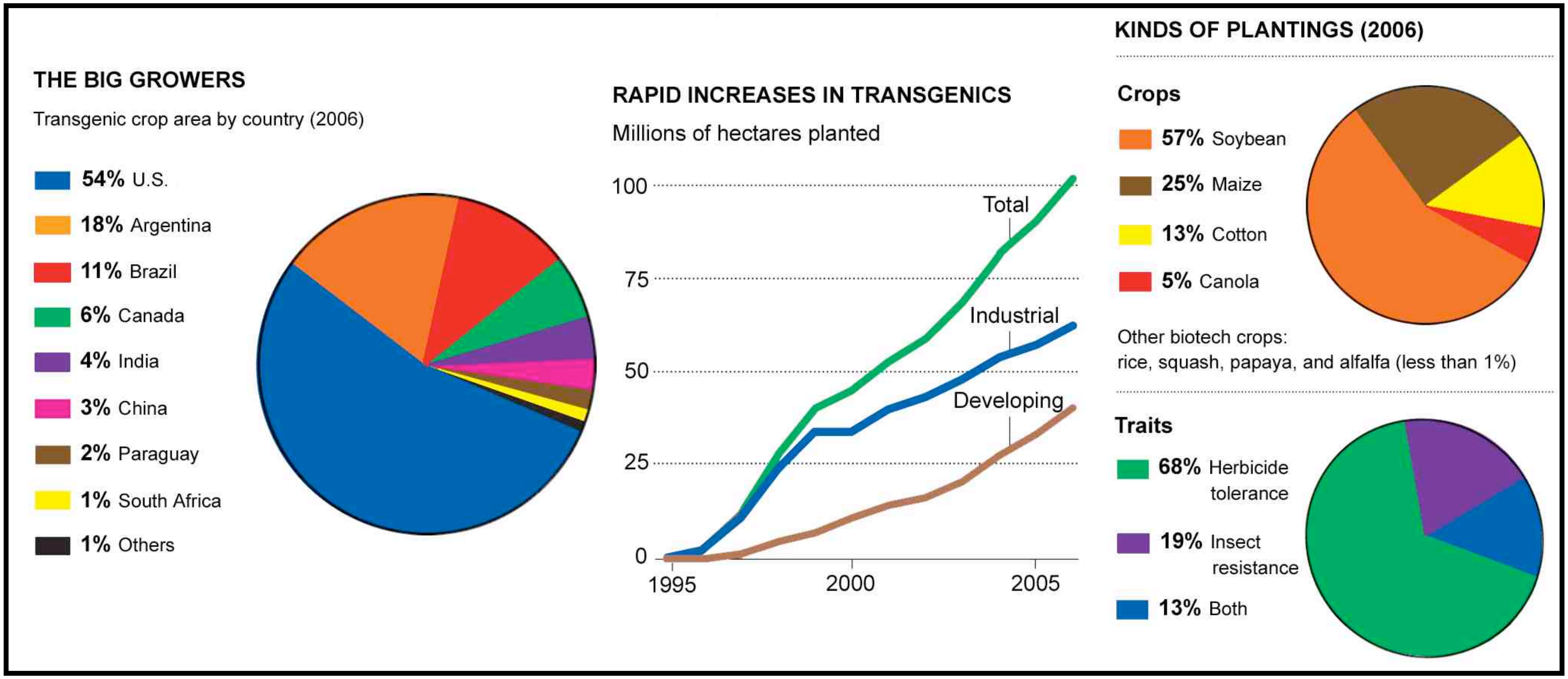
*Crops as Factories & *Vaccines**

Detoxifying Contaminated Soils

Crops to Clean Environment

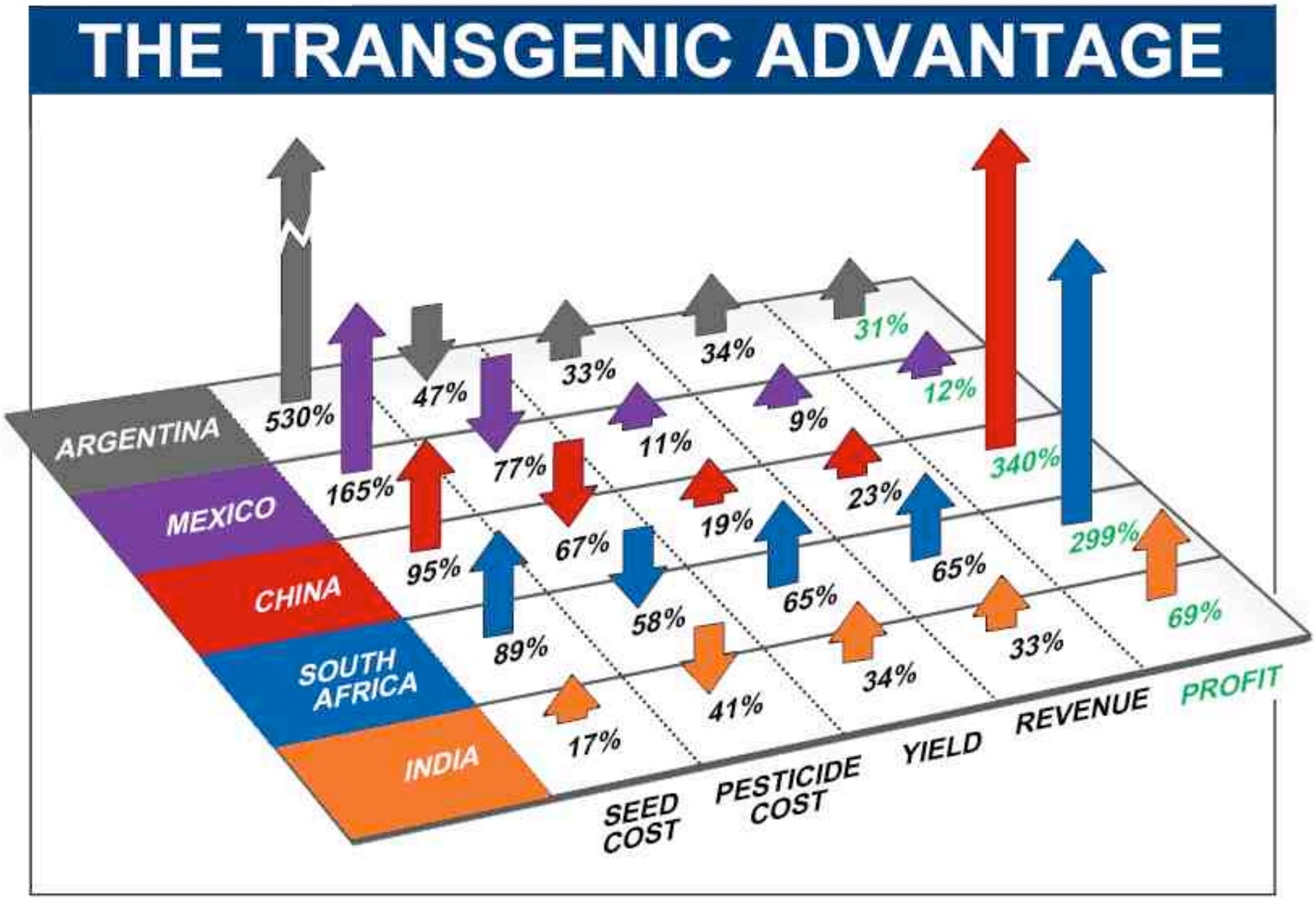
But Only a Few Have Helped Generate New Crops!
The "Simple Ones With Economic Drivers"

One Way is to Use These New Traits in Engineered Crops That Farmers Have Adopted Faster Than Any New Agricultural Technology In the Past 100 Years!



Over One Billion Acres of Bioengineered Crops Have Been Grown World-Wide Since 1996 and 250 Million Acres in 2007

Engineered Crops Have Increased Yields, Reduced Pesticide Use, and Increased Incomes of Farmers in the Developing World

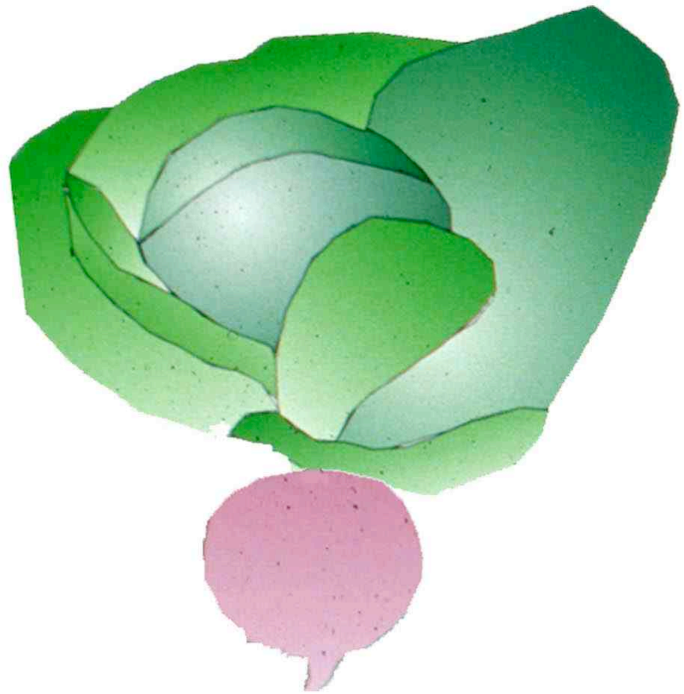


United Nations FAO Report No. 35, 2003-04; Scientific American, September, 2007

However…There's a Battle Raging to Get Bioengineered Crops Adopted in Many Parts of the World


Professor Frank Furedi, University of Kent, England

The End……………..



….or is it the Beginning?

HC70A-Genetic Engineering in Medicine, Agriculture, & Law

http://www.oid.ucla.edu/webcasts/courses/2007-2008/2008winter/hc70a-1

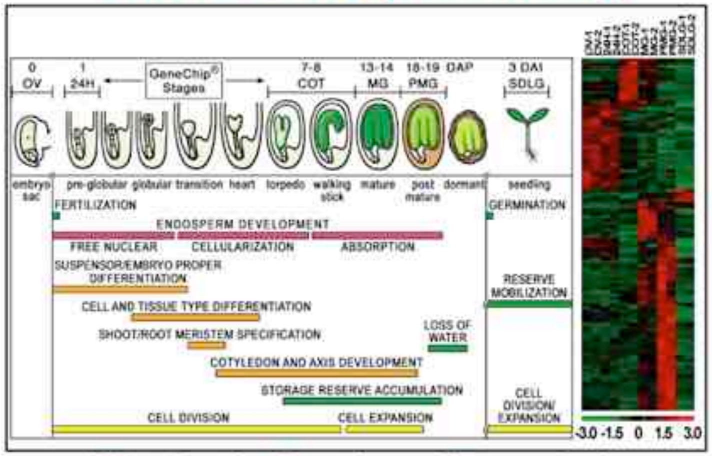
① **THE BEGINNING: Learning Molecular Biology Techniques and Choosing Arabidopsis Transcription Factor Genes to Knock Out**

② **Using BioInformatics to Study the Features of Transcription Factor Genes Chosen to Be Knocked Out**

③ **Using PCR to Screen Plant Populations for Knock-Outs in Transcription Factor Genes**

⑧ **THE END: Preparing a Power Point Presentation of Results and Giving a Talk at the Final Class Symposium**

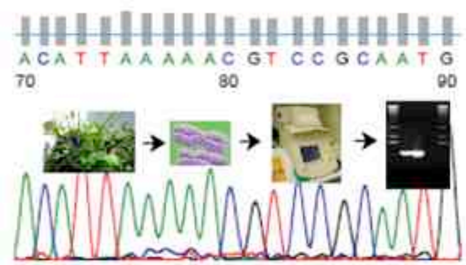
HC70AL
Gene Discovery Laboratory



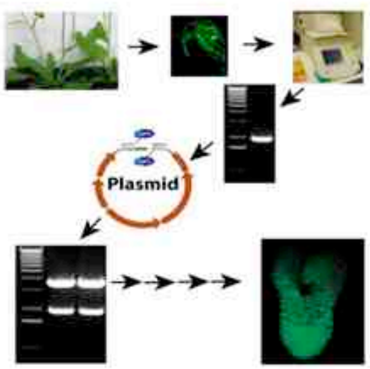
What Are the Functions of Transcription Factor Genes That Are Active During Embryo and Seed Development?

(WebBOOK)

④ **Using DNA Sequence Analysis to Verify the T-DNA Insert Sites in the T-DNA Knock-Out Genes**

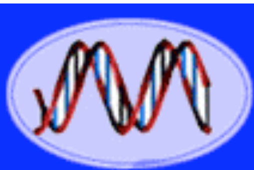


⑦ **Cloning Promoters of Transcription Factor Genes Chosen to Be Knocked Out and Using Green Fluorescent Protein to Study Their Activity During Seed Development**



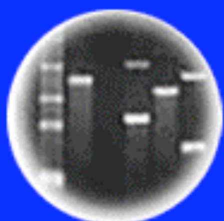
⑥ **Using a Dissecting Microscope and a Microscope with Nomarski Optics to Examine the Phenotype of Embryos and Seeds in Knock-Out Lines**

⑤ **Using RT-PCR and GeneChip Analysis to Study Transcription Factor Gene Activity in Seeds and Other Plant Organs**



DNA
Genetic Code of Life

Entire Genetic Code
of a Bacteria



DNA Fingerprinting

Cloning: Ethical Issues
and Future Consequences

Plants of Tomorrow

Going Long Distance
Winter 2009!

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A Model For Cross-Campus Interactive Learning