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# Next Generation Bioenergy

## *Technologies for Feedstocks for Cellulosic Ethanol Production from Non-Food Sources*

**German Spangenberg**

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MPB CRC

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## World Energy Consumption – Status and Forecasts

- **Fossil fuels account for 80% of the world energy consumption and their use is the main cause of global warming**
- **World primary energy consumption grew on average 2.1% per year over the last 30 years**
- **Over 10 billion tons oil equivalents of primary energy are consumed per year**
- **1.6 billion people, a quarter of the world population, has no access to electricity**
- **Conventional oil reserves will inexorably concentrate in the Middle East, which holds 65% of the world proven reserves**
- **Coal is the most abundant fossil energy for the next century**

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## Rationale for Bioenergy on Global Basis - 1

***Bioenergy is being targeted as key contributor to global fuel supplies, displacing fossil fuels, in the decades ahead - since***

- **Population is increasing**
- **Per capita GDP is increasing (standard of living)**
- **World energy consumption is rising**
- **Burning of fossil fuels is a major source of greenhouse gases**
- **Fossil energy resources are finite**





## Rationale for Bioenergy on Global Basis - 2

- **Petroleum resources are most limiting**
- **Petroleum is the major source of transportation fuel**
- **Modern economies cannot function without abundant and inexpensive transportation fuel**
- **The majority of proven petroleum reserves are in the politically unstable Middle East**

***Alternative, renewable and sustainable bioenergy must be developed if we intend to maintain our high standard of living in the longer term.***

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## Energy in Victoria - Challenges

*Victoria is facing significant environmental challenges to the economic advantages it derives from utilisation of its very low-cost brown coal resources - since*

- Victoria accounts for 22% of Australia's greenhouse gas emissions
- Approximately 52% of these arise from the use of brown coal for electricity generation in the State
- Need to contain greenhouse gas emissions from supply and use of energy to develop over time a sustainable energy sector

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## Feeding the World

- Human population doubled since 1960 to 6 billion
- World population predicted to increase to 8 billion by 2030 and to 9 billion by 2050
- In the next 2 generations the world will consume twice as much food as consumed in the entire history of humankind
- Multiple new technologies of food production created and adopted to keep up with population growth

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## Sustainable Bioenergy Development

- Need to follow long term strategy of decoupling the biofuel and food industries
- Next generation of biofuels will need to come from non-food sources
- Produced from dedicated bioenergy crops
  (e.g. low input, water and nutrient use efficient perennial grasses – not competing for arable land for cropping)
- Produced from by-products of other human activities
- Use of enzyme fermentation of crop residues such as straw and grass biomass as feedstocks for cellulosic ethanol

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## Sustainable Bioenergy Development - Cellulosic Ethanol

- About half of the above ground biomass of grain crops is 'wasted' as straw
- Globally, ca. 2 billion tons of wheat, rice and maize straw are produced annually
- Australia could generate c. 40 M tons cereal residue per year
  (as feedstock potential >15 BL bioethanol)
- Biodegradation of cellulose and hemicellulose in straw is heavily prevented by lignin

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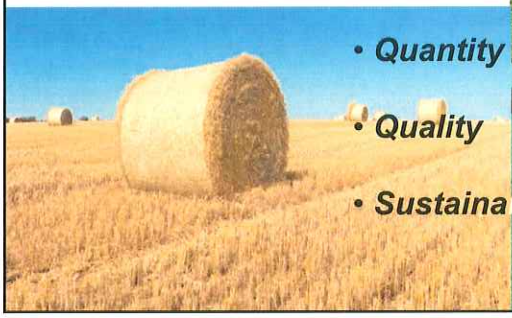
## Cellulosic Ethanol – Feedstock Issues

- **Solar collection efficiency**
- **Biomass conversion**



- ***Quantity***
- ***Quality***
- ***Sustainability***

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## Solar Collection Efficiency – Requirements and Issues

- **High energy content plants** (cellulose)
- **High 'cellulose-intensity' crops** (available cellulose/hectare yield)
- **Minimisation of agricultural input requirements** (water, fertilizer)
- **Tolerance to abiotic stress** (low/irregular rainfall, salinity)
- **Seasonal variation in biomass production**
- **Deliberate development of perennials**
- **Feedstock diversity to minimise supply disruption**
- **Suitability of the local climate/environment**

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## Biomass Conversion – Requirements and Issues

- Convert biomass into 'free sugar' in time, energy and resource efficient manner
- Achieved by accessing cellulose and hemicellulose and exposing them to fermentation using enzymes
- Problems:
  a) lignin interferes physically & chemically with enzyme activity
  b) cellulose hydrolysis is slow and costly
- Potential Solutions:
  a) reduce lignin content and modify its composition
  b) enable plants to produce their own hydrolysis enzymes

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## Technologies for Feedstocks for Cellulosic Ethanol Production from Non-Food Sources

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- Improvement of agronomic traits for sustainable bioenergy plant production systems, optimising
  - biomass yield
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  - biotic and abiotic stress tolerances
  - nutrient use efficiency
  - others
- Production of cell wall polysaccharides degrading enzymes in plants
  - enhanced cellobiohydrolases
  - enhanced endoglucanases
- Generation of value added products in plant biomass

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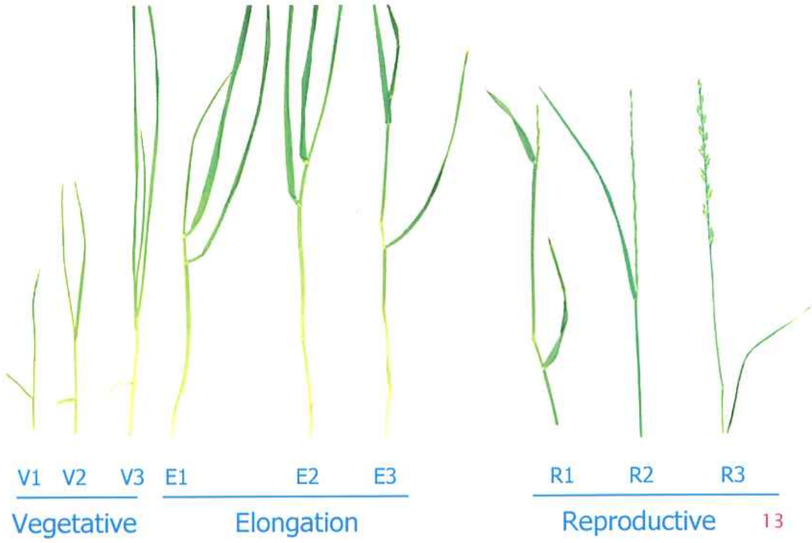
## Cell Wall Modification to Assist in Deconstruction - 1

### Developmental Stages in Perennial Grasses

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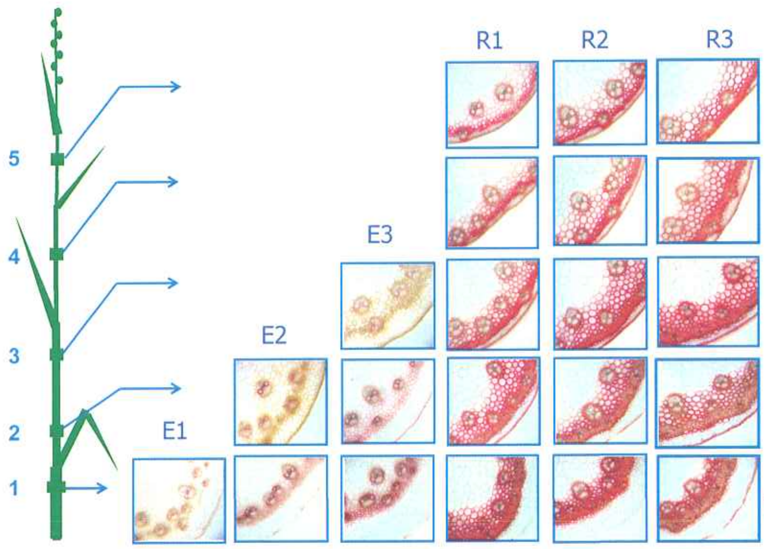
## Cell Wall Modification to Assist in Deconstruction - 2

### Lignin Deposition in Perennial Grasses

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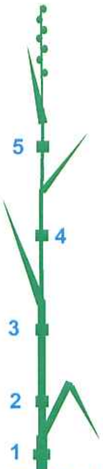
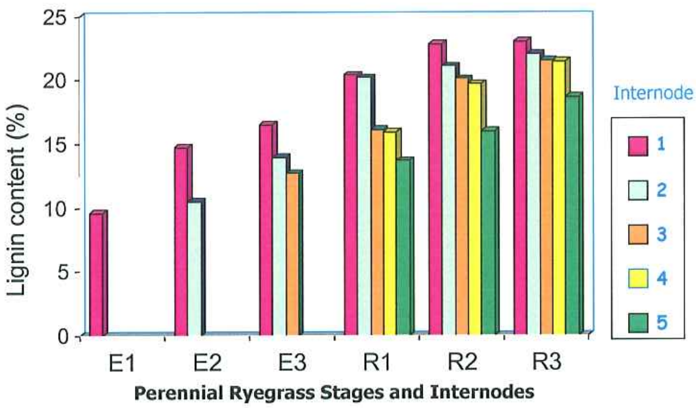
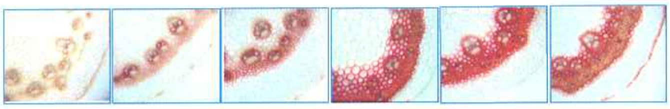
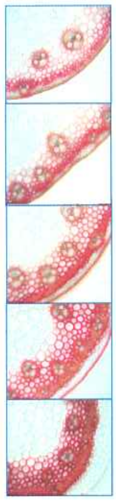
## Cell Wall Modification to Assist in Deconstruction - 3

### Lignin Content in Perennial Grasses





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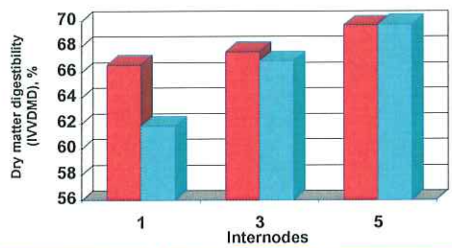
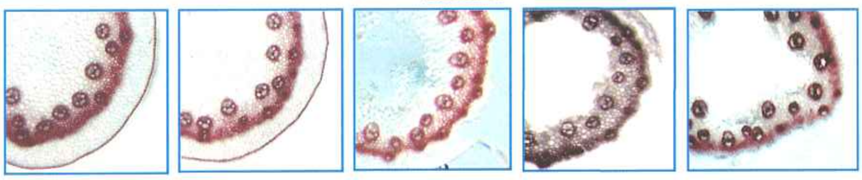
## Cell Wall Modification to Assist in Deconstruction - 4

### Lignin Interferes with Cell Wall Fermentation




Incubation of perennial ryegrass in ruminal fluid

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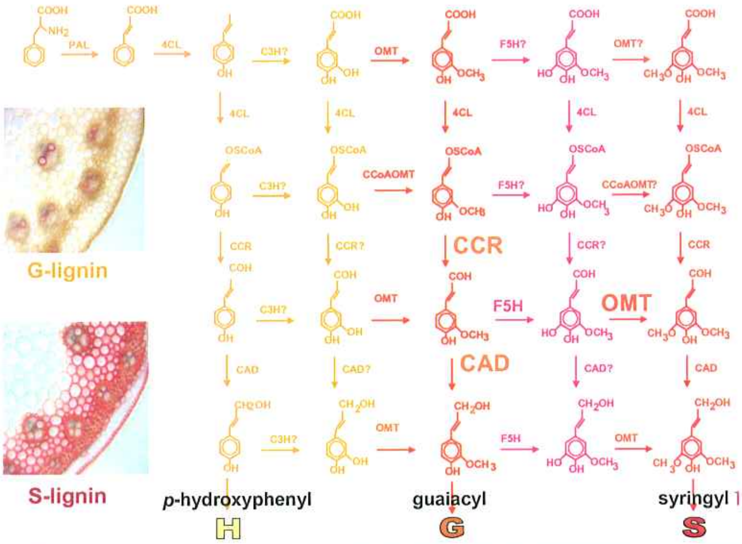
# Cell Wall Modification to Assist in Deconstruction - 5

## Lignin Biosynthesis in Grasses

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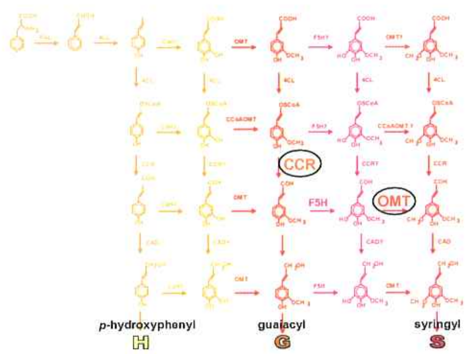
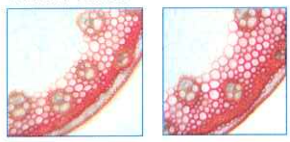
# Cell Wall Modification to Assist in Deconstruction - 6

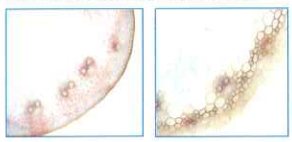
## Technology 1:
## Genetic Modification Technology for Cell Wall Modification in Wheat Straw and Perennial Grasses




*Control Grass*



*GM Grass with Reduced OMT*



*GM Grass with Reduced CCR*

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## Technologies for Feedstocks for Cellulosic Ethanol Production from Non-Food Sources

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- **Improvement of agronomic traits for sustainable bioenergy plant production systems, optimising**
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    - biotic and abiotic stress tolerances
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    - others
- **Production of cell wall polysaccharides degrading enzymes in plants**
    - enhanced cellobiohydrolases
    - enhanced endoglucanases
- **Generation of value added products in plant biomass**

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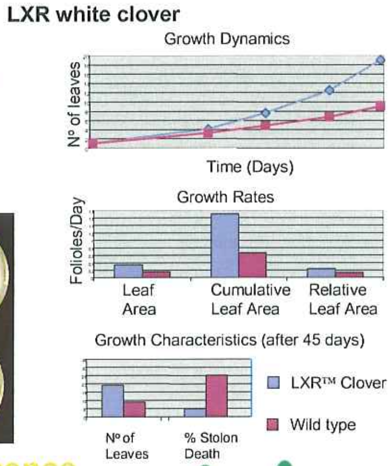
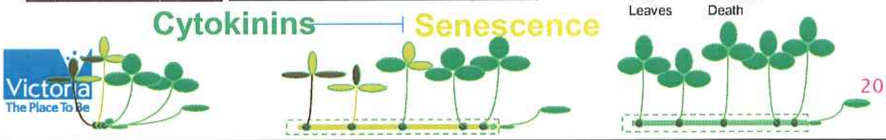
## Agronomic Traits for Sustainable Bioenergy Plant Production - 1

### Optimised Biomass Yield and Vegetative Growth Patterns

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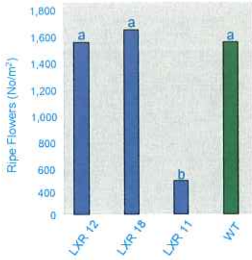
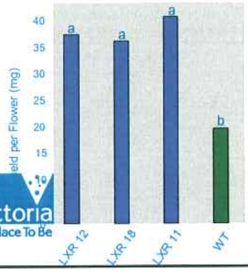
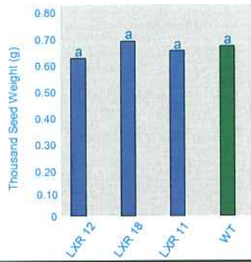
## Agronomic Traits for Sustainable Bioenergy Plant Production - 2

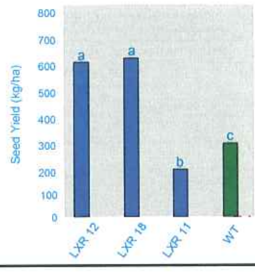
### Technology 2:
### Genetic Modification Technology for Yield Enhancement in Wheat and Perennial Grasses

Field evaluation of LXR white clover

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## Technologies for Feedstocks for Cellulosic Ethanol Production from Non-Food Sources

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  - others
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- **Generation of value added products in plant biomass**

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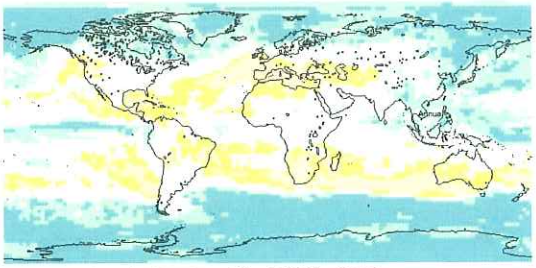
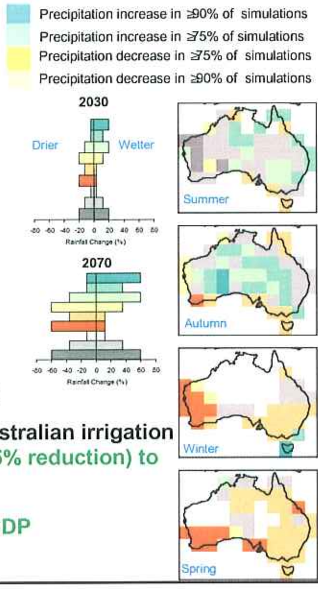
## Agronomic Traits for Sustainable Bioenergy Plant Production - 3

### Climate Change and Variability

- **Projected climate change implications for Australia suggest**



*Report to the Australian Greenhouse Office, DEH, March 2005*




- **A likelihood of decreasing rainfall over most of Australia**
  - **GDP scenario losses due to reduction in Australian irrigation allocations estimated between $136 million (5% reduction) to $751 million (20% reduction)**
  - **Drought subtracted c. 1% from Australia's GDP in 2002/03; equal to ca. $6.6 billion**

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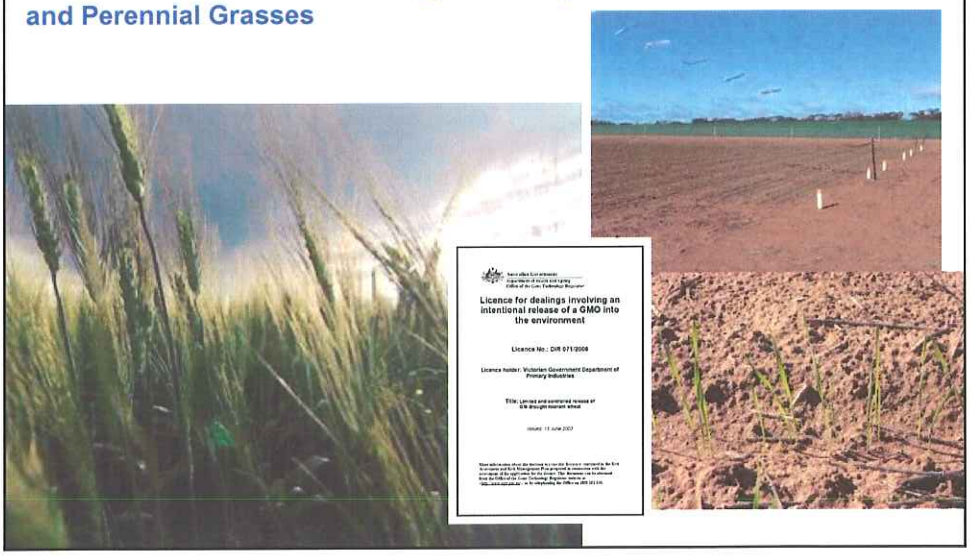
## Agronomic Traits for Sustainable Bioenergy Plant Production - 4

### Technology 3:
### Genetic Modification Technology for Drought Tolerance in Wheat and Perennial Grasses



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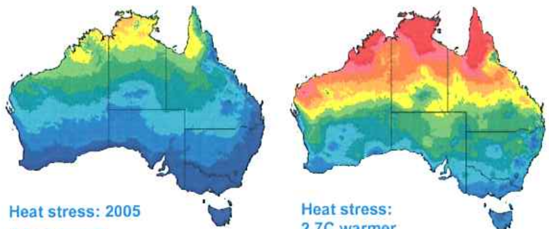
## Agronomic Traits for Sustainable Bioenergy Plant Production - 5

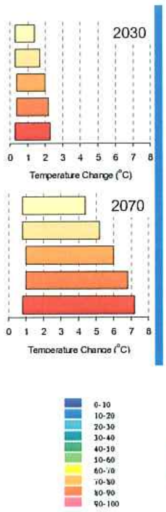
### Climate Change and Variability

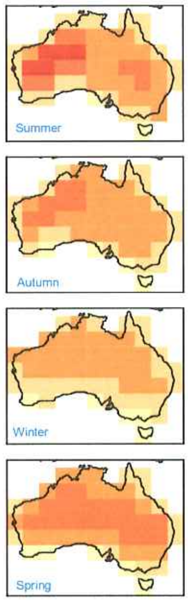
- **Projected climate change implications for Australia suggest**
- **Annual average warming over much of inland Australia of 1-6°C by 2070**
- **Increased heat stress frequency**



Heat stress: 2005

Heat stress: 2.7C warmer

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*Report to the Australian Greenhouse Office, DEH, March 2005*

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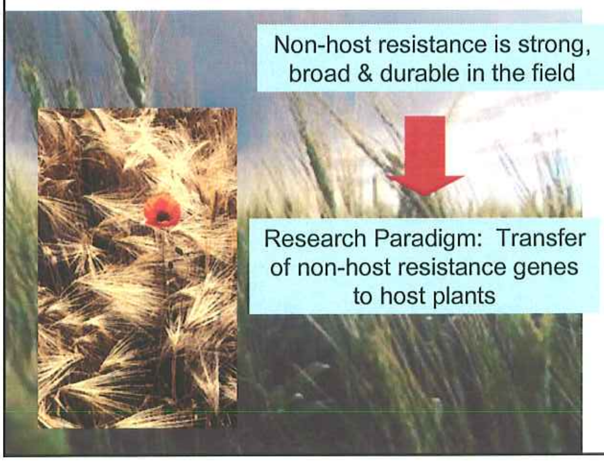
## Agronomic Traits for Sustainable Bioenergy Plant Production - 6

### Non-Host Resistance

**Plants Are Surprisingly Healthy!**




**Estimated national trait values of diseases in wheat**

- **Stripe rust $102 million**
- **Crown rot $90 million**
- ***Septoria tritici* $86 million**
- ***Septoria nodorum* $83 million**
- **Stem rust $57 million**
- **Leaf rust $56 million**

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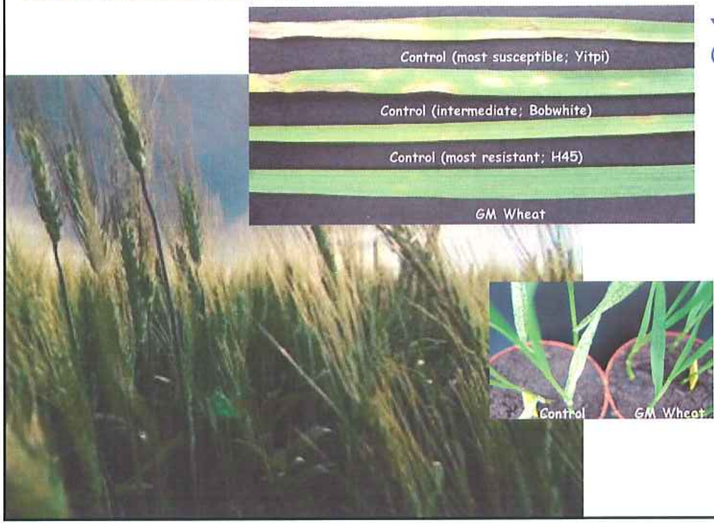
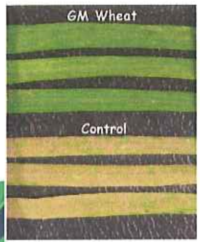
## Agronomic Traits for Sustainable Bioenergy Plant Production - 7

### Technology 4:
### Genetic Modification Technology for Biotic Stress Tolerance in Wheat and Perennial Grasses




**Yellow leaf spot**
*(Pyrenophora tritici-repentis)*




**Powdery mildew**
*(Blumeria graminis)*

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## Technologies for Feedstocks for Cellulosic Ethanol Production from Non-Food Sources

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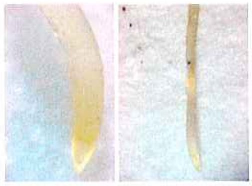
## Agronomic Traits for Sustainable Bioenergy Plant Production - 8

### Nutrient Use Efficiency

- P forms insoluble unavailable compounds
- 30 million tons of P fertiliser applied yearly worldwide
- Australian farmers spend $600 million in P fertiliser per year
- Up to 80% of applied P fertiliser lost
- $10 billion of P in Australian soils



OA-Transgenic

Control

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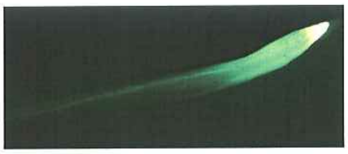
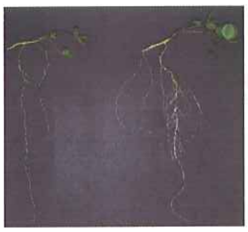
## Agronomic Traits for Sustainable Bioenergy Plant Production - 9

### Technology 5:
### Genetic Modification Technology for Nutrient Use Efficiency in Wheat and Perennial Grasses

Root tip-prevalent promoter from white clover (*Tr*PT1::gfp)

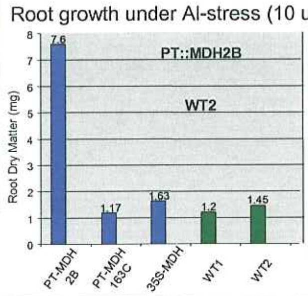



Isogenic Control vs Transgenic 500 uM Al



Isogenic Control vs Transgenic 500 uM Al

Root growth under Al-stress (10 uM)

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