Air Pollution Abatement Implications of Advanced Cellulosic Biorefineries

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Presentation Outline

- The PureVision biorefining process
- Sugar platform – Quantitative analysis of ethanol production
- Pulp and paper platform – Qualitative assessment
- Conclusions & recommendations for future work

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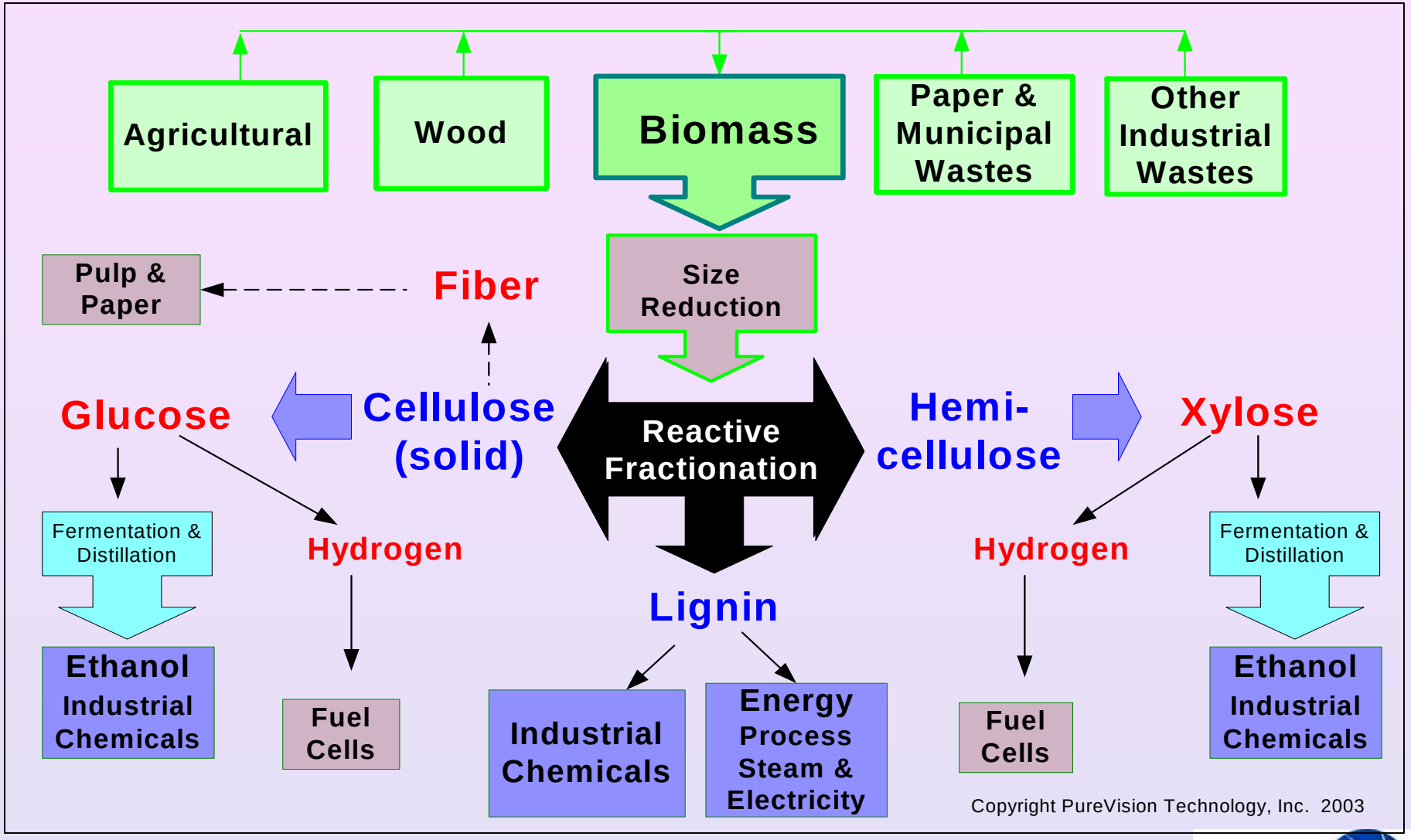
PureVision Biorefinery Schematic



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U.S. Ethanol & Pulp Production

- Cellulosic biorefining to sugars in infancy
- U.S. ethanol production from starch
  - +4 billion gallons in 2005 — all corn based
  - Future ethanol production from biomass-derived sugars
- Pulp and paper production
  - About 57 million t/yr of pulp, U.S. the largest producer and consumer
  - Kraft process dominates
    - >70% of North America pulping capacity
    - ~ 700 lb per capita per year

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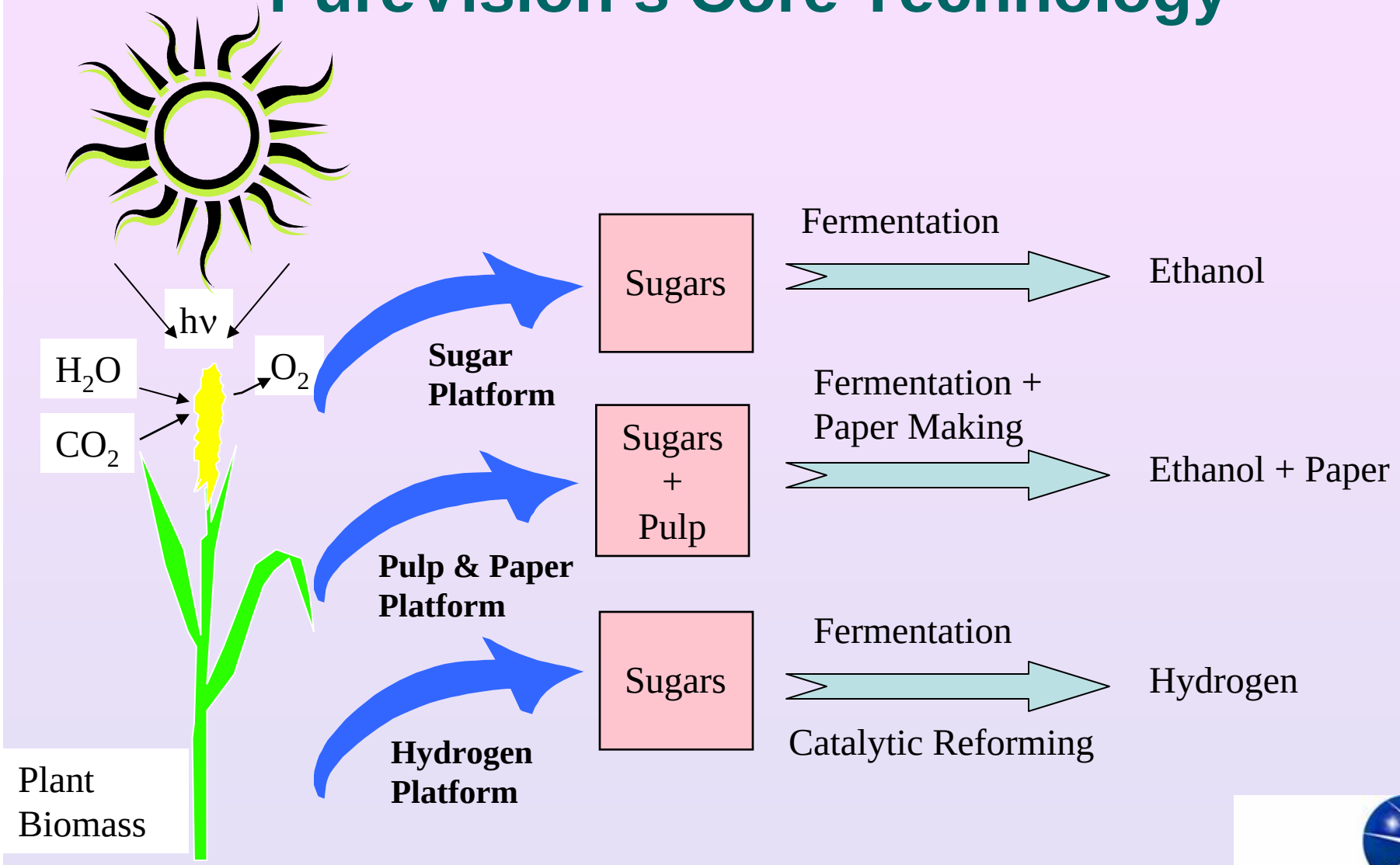
Routes for Biomass Refining Using PureVision's Core Technology



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Benefits of PureVision's Process

- **New processing regime**
  - Employs countercurrent processing
  - Closed loop approach minimizes waste and minimizes reagent use
  - Separates biomass into 3 distinct product streams
  - Produces a "pure" cellulose stream
  - Produces a non-sulfur, low molecular weight lignin
- **Sugar platform**
  - Reduces enzyme use for ethanol production
  - Reduces conversion time
- **Pulp and paper platform**
  - Non polluting process, reduces water demand
  - Provides higher-value lignin co-product

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Corn Stover Feedstock

Component		Wt%	
Ethanol soluble extractives		3.63	
Sucrose		0.00	
Water soluble extractives		3.20	
Glucan	Fraction 3	35.27	←
Xylan	Fraction 1	21.80	←
Galactan		1.81	
Arabinan		3.06	
Mannan		0.28	
Lignin	Fraction 2	16.27	←
Structural inorganics		3.87	
Ext inorganics		1.63	
Protein		2.31	
Acetyl		2.01	
Uronic acid		3.57	
	Total	98.71	

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Key Process Targets

Sugar	Overall Ethanol Fermentation Yield, %
Glucose	90
Xylose	85
Mannose	90
Galactose	90
Arabinose	85

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Plant Capacity & Energy Output

Biorefinery producing ethanol & energy

Parameter	Value	Units
Biomass feedstock	500	t/day
	182,500	t/yr
Ethanol production	65	million L/yr
	17	million gal/yr
	51,700	t/yr
Methane production	12.5	t/yr
Electricity production	5.4	MW

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Methodology
Estimating Environmental Impacts

- Operating plant vs. total system (life-cycle based emissions)
  - Only operating plant considered for this preliminary analysis
  - End products compared with fossil products on an energy-equivalent basis
- Ethanol vs. gasoline combustion
  - CO_2, CH_4
- Electricity generation from lignin vs. coal
  - CO_2, SO_2 and NO_x
- Biogas vs. natural gas combustion
  - CO_2

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Emissions Avoided on Energy-Equivalent Basis

- Basis: 500 t/d biorefinery
- Ethanol vs. gasoline combustion
  - **Fossil CO_2 reduction: 92,000 t/yr**
- Power generation with lignin vs. coal
  - **Fossil CO_2 reduction: 56,600 t/yr**
  - **SO_2 reduction: 1,300 t/yr**
  - **NO_x reduction: 500 t/yr**

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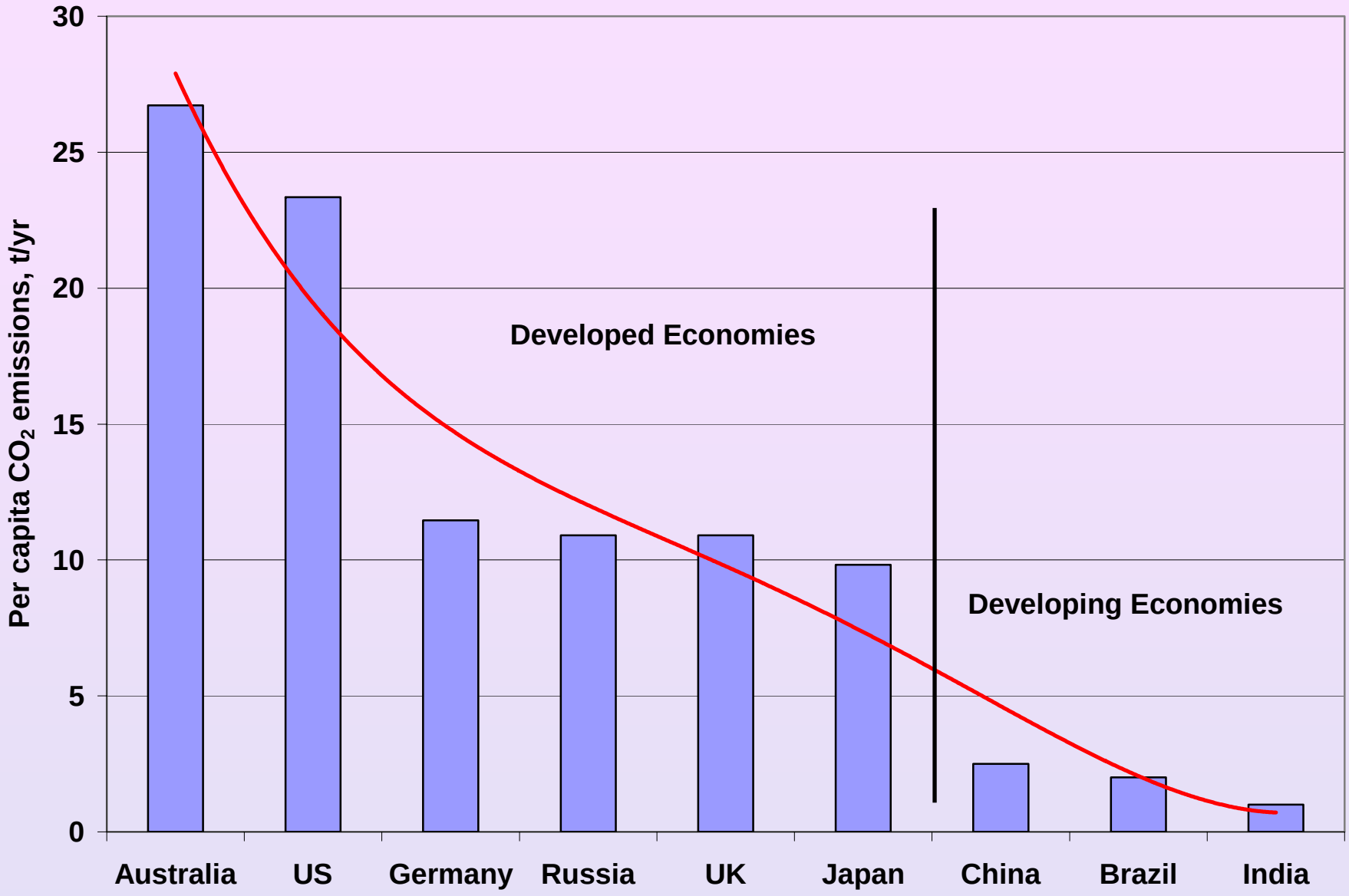

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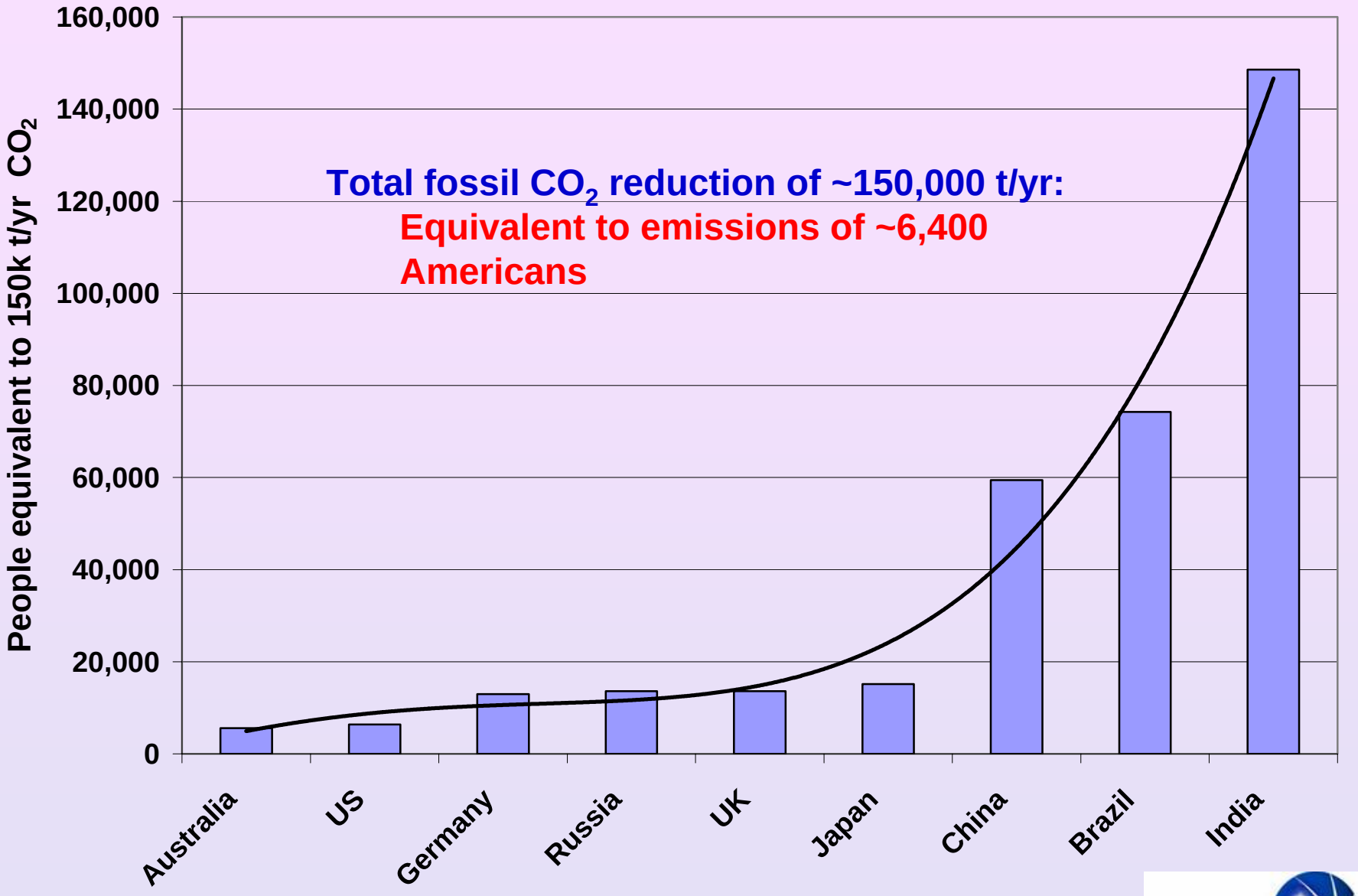

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Externalities

- Markets do not take into account
  - Depletion of scarce natural resources
  - Denigration of the environment
- Such market failure = “externality”
  - Specific economic values remain “external” to the market’s price-setting mechanism
- True price of product or service should capture cost of externalities
- GHG emissions not regulated in the U.S.

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Cellulosic Ethanol
Monetization of Externalities & Trading of Criteria Pollutants

Emissions Avoided	$/t	t/yr	Million $/yr	¢/gal
Ethanol				
CO_2	19*	92,000	1.8	10.5
Power				
CO_2	19*	56,600	1.1	6.6
SO_x	610**	1,300	0.8	4.8
NO_x	1,800**	500	0.9	5.5
				27

*European Energy Exchange
**Platts index

True cost ($/gal) = Production cost ($/gal) – 0.27

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Pulp and Paper Platform

Environmental Burdens of Kraft Pulping Process

- Air emissions in kg/t ADP (air dried pulp)
  - Hydrogen sulfide, methyl mercaptan, dimethyl sulfide and dimethyl disulfide: 0.3-3
  - Particulate matter: 75-150
  - Sulfur oxides: 0.5-30
  - Nitrogen oxides: 1-3
  - Volatile organic compounds (VOCs): 15
- Liquid effluents
  - Chlorinated organic compounds (which may include dioxins, furans, and others, collectively referred to as absorbable organic halides or AOX): 0 to 4

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Emissions from Pulp and Paper Manufacturing

Parameter	Maximum recommended value
Air Emissions	
Particulate matter	100 mg/Nm^3 (for recovery furnace)
Hydrogen sulfide	15 mg/Nm^3 (for lime kilns)
Total sulfur emitted Sulfite mills Kraft and other mills	 1.5 kg/t ADP 1.0 kg/t ADP
Nitrogen oxides 2.0 kg/t ADP	2.0 kg/t ADP
Liquid Effluents	
COD	COD 15 kg/t
AOX	2 kg/t ADP
Total P	0.05 kg/t ADP
Total N	0.4 kg/t ADP

World Bank, Environment Department. 1996. "Pollution Prevention and Abatement: Pulp and Paper Mills." Technical Background Document.

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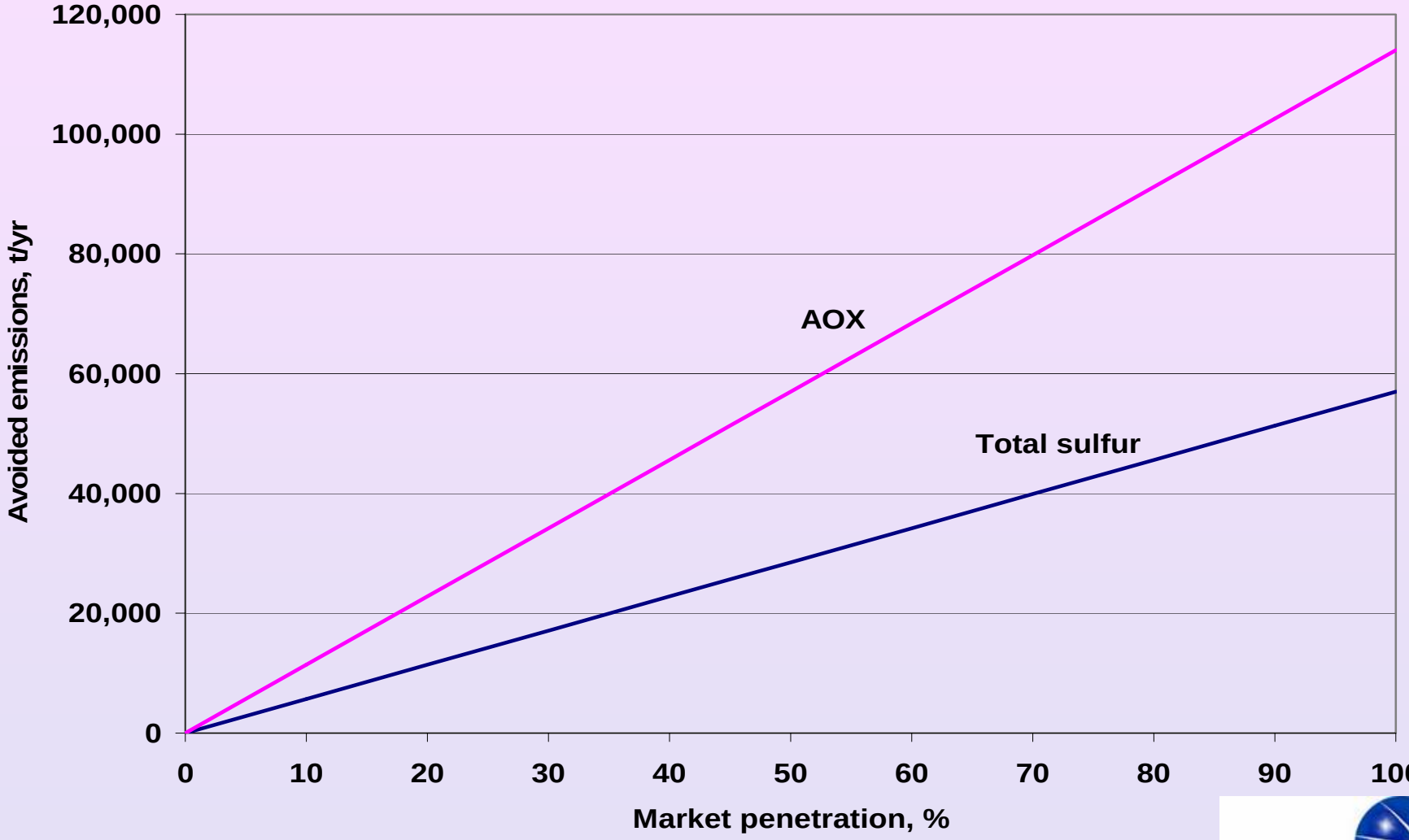
Potential Avoided Emissions
PureVision Process vs. Kraft Process



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Greenfield Pulp Production via PureVision Process

- No sulfur
  - Hydrogen sulfide
  - Methyl mercaptan
  - Dimethyl sulfide/disulfide
- No chlorine
  - Chlorophenolics
  - Dioxins (PCDD) and Furans (PCDF)
  - Chloroform and other neutral chlorinated compounds
- Bioethanol produced from xylan fraction
  - Lower GHG emissions
- Benefits need quantification

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Conclusions

- **PureVision reactive fractionation technology**
  - Novel process employs countercurrent processing for cellulosics
  - Processing biomass-to-pulp, sugars and ethanol in infancy
  - 3 product streams: hemicellulose, lignin, cellulose
  - Reduced reagent use, minimal waste products
- **Sugar platform (ethanol) analyzed**
  - Significant potential for GHG mitigation
  - True price of ethanol lower by 27 ¢/gal if cost of externalities captured
  - Total mitigation potential of corn stover: 80 M t CO_2/yr for 538 PureVision biorefineries @ 500 t/day
- **Pulp and paper platform**
  - Benefits are evident but need quantification

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Priorities and Future Work

- Scale-up to 4 ton per day prototype
- Beginning to work with new feedstocks
- Sugar platform
  - Demonstrate process yields at larger scale and with other feedstocks
  - Conduct LCA and Aspen economic modeling
- Pulp & paper platform
  - Analyze and quantify environmental benefits
  - Continue work with woods and agricultural residues
- Continue to attract strategic partners with the focus on developing commercial projects

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GHG Mitigation: A Global Issue

Source: NASA

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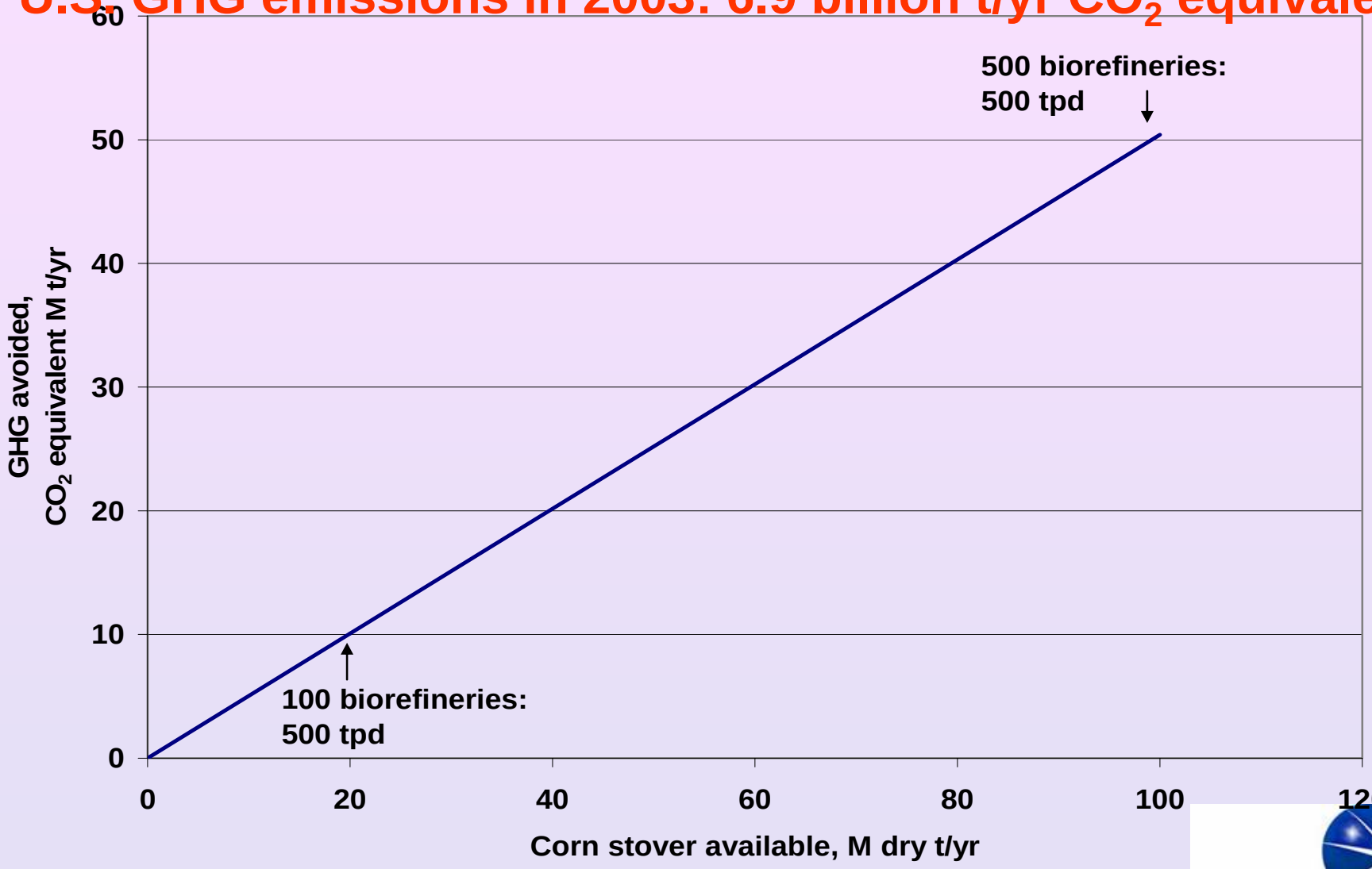
Potential Impact: Corn Stover

U.S. GHG emissions in 2003: 6.9 billion t/yr CO_2 equivalent



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