Industrial Technology Program

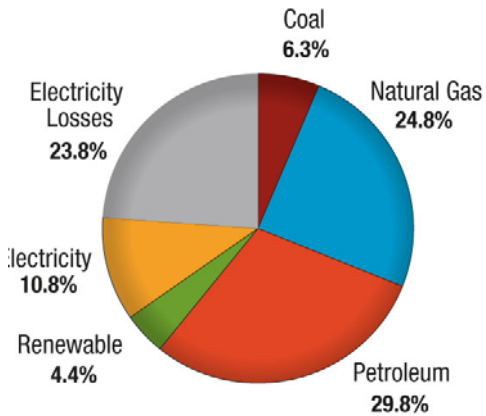
DOUGLAS KAEMPF, PROGRAM MANAGER
douglas.kaempf@ee.doe.gov
(202) 586-5264

VENTURE CAPITAL TECHNOLOGY SHOWCASE
AUG 21 AND 22, 2007

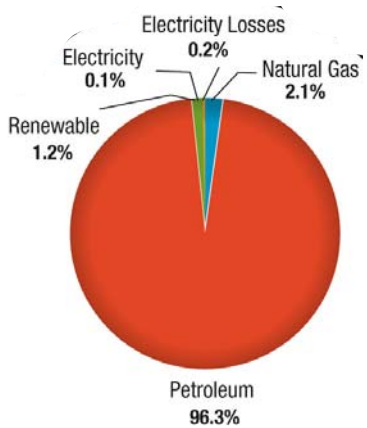
Industrial Sector Offers Large Opportunities to Achieve National Energy and Emission Goals

Industrial Sector

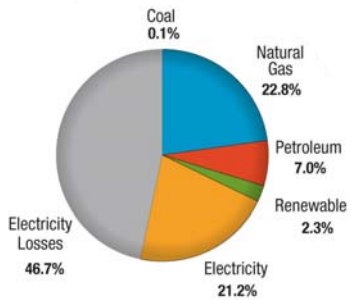
>200,000 sites
14.3 million jobs
$5,900 billion shipments
$ 980 billion exports



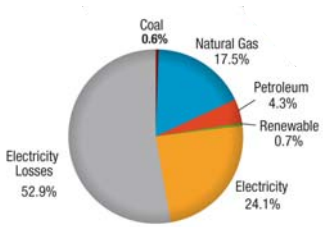
Industrial Sector
Energy Consumption
32.0



Transportation Sector
Energy Consumption
28.1



Residential Sector
Energy Consumption
21.9



Commercial Sector
Energy Consumption
18.0

Largest Energy Consumer

Most Diverse Energy Demand

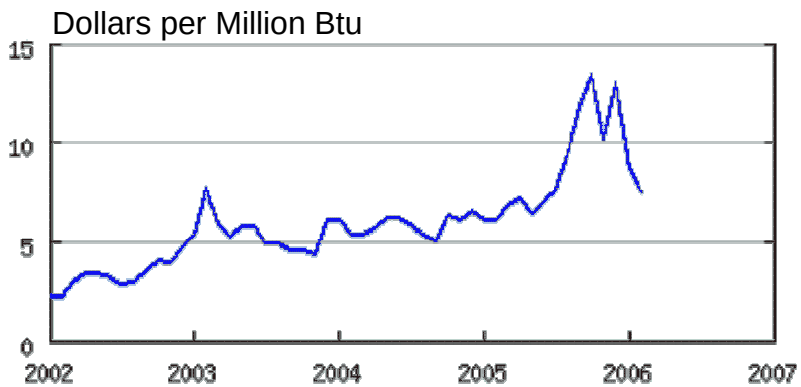
Largest Opportunities for
- **Energy Reduction**
- **Emission Reductions**
- **Fuel Flexibility**

Enhanced Energy Security
Reduction of Imported Energy
Reduction of Emissions

Challenges for Energy-Intensive Industries

- Industry concern about energy prices and volatility
- Influence of the emerging economies on competitive landscape
- Restricted ability for individual firms to make needed investments in R&D and
- Capture “game-changing” scientific advances

Natural Gas Prices, Henry Hub, LA



Delivering Innovative Technology Solutions

Partnerships

Collaborative R&D

- Energy-intensive Process Technologies
- Crosscutting Technologies

Technology Delivery

- Energy Savings Assessments
- Training & Tools

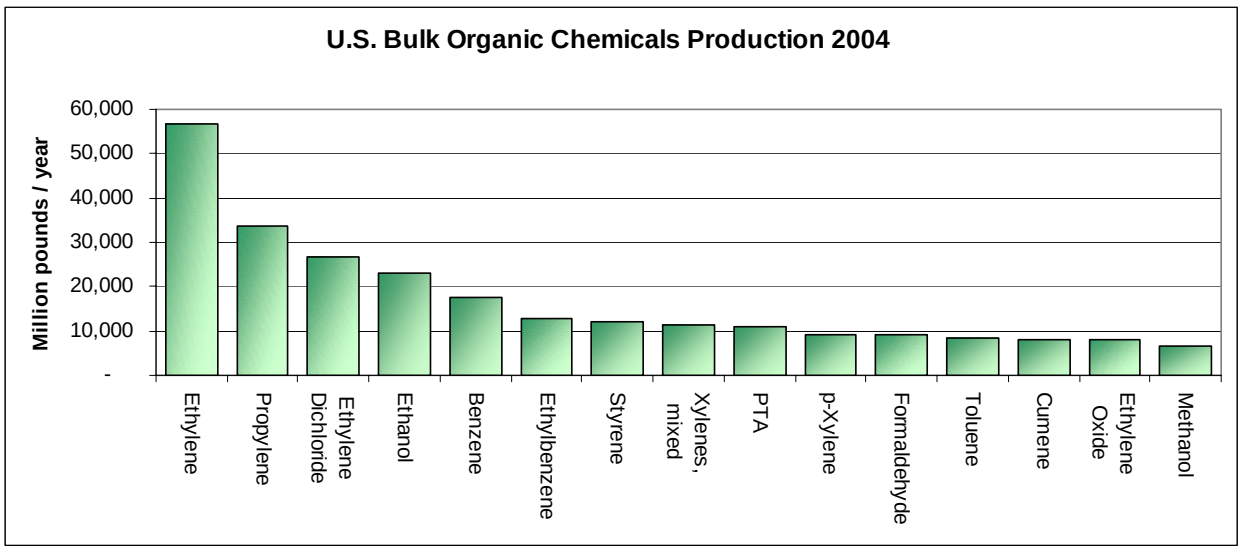
Bulk Chemical Manufacturing

Problem:

- Most chemical reactions are incomplete, resulting in left over feedstock, and produce undesirable byproducts which consume precious feedstock. The resultant mixture of left over feedstock and byproducts necessitates complex and energy intensive purification/separation steps.
- Ethylene is the largest volume organic chemical produced in the US (**56.6 billion pounds/year, $22 Billion/year**) and the world (250 billion pounds/year).
- Ethylene is the **precursor to** thousands of products, including **polyethylene, polyvinyl chloride, ethylene glycol, and polystyrene**. World market growth is expected to be 4.3%.
- The ethylene reaction yield is limited by the chemical thermodynamics to ~65%. The unreacted feedstock and byproducts must be separated out and recovered which accounts for nearly 70% of the capital costs of the plant.

Solution:

Technologies that change the thermodynamics for increased yield, and reduced byproduct production and operating costs.

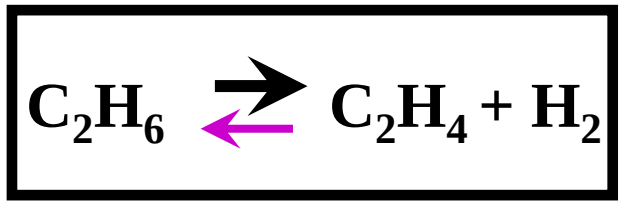


Ethylene producers separate, purify and internally recycle over 20 billion pounds a year of material that they never market. They consume well over 250 TBtu/yr to do this extra work.

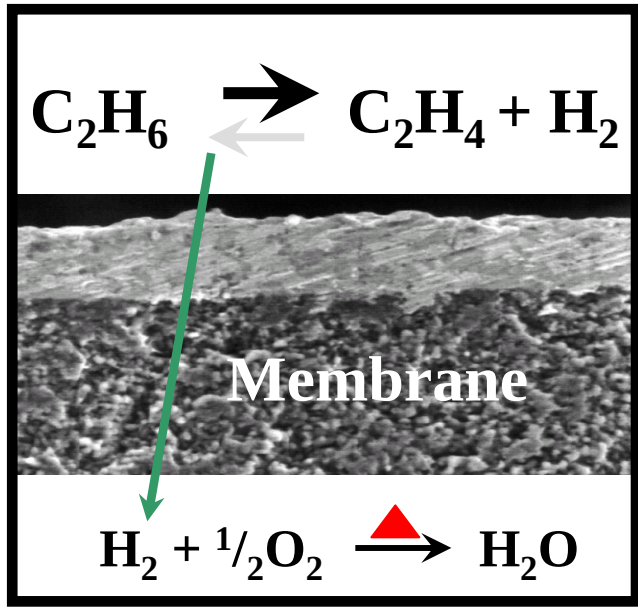
Novel Membrane Technology for Green Ethylene Production

- Problem: Feedstock and energy costs are increasing. Currently the feedstock conversion is thermodynamically limited to about 65%. Downstream separation/purification and recovery of the byproducts is energy intensive and accounts for ~70% of the capital costs.
- Description: Hydrogen Transport Membrane – Increases the conversion rate to 74% by selectively removing hydrogen, recovering the hydrogen energy and eliminating oxide byproducts **(No CO_2, CO or NOx emitted).**
- Impact: Lower feedstock use, energy requirements, and separations and purifications, potentially **reducing operational and capital costs by >12%.**
  - Market: U.S. ethylene production is a $**22 Billion/year** industry.
- IP: Argonne has a patent on membrane materials and a patent application on this novel process. Technology is available for licensing.
- Status: Proof-of-concept demonstrated.
  - Reduction to practice – Will require development of process design, engineering and costs analysis for full-scale operations, fabrication of full-scale membrane devices, and demonstration at pilot scale.
  - Availability – 3-5 years (est.) to prepare for full implementation
  - Capital Needs - Significant capital costs (>$10MM est) required to modify/change furnace design.

Traditional Production
limited by reverse reaction



Membrane Process
changes reaction, adds heat



First Name: U. (Balu)	Last Name: Balachandran	Argonne
Phone:630-252-4250	E-mail: balu@anl.gov	

Catalyst Manufacturing by Atomic Layer Deposition

•Problem: The costs for thermally producing chemicals is impacted by low conversion rates, high energy consumption and complicated purification/separations. To-date few catalysts out-perform bulk chemical thermal processing.

•Description: Atomic layer deposition (ALD) is a layer-by-layer coating technology that provides precise **control over composition and morphology of catalysts.**

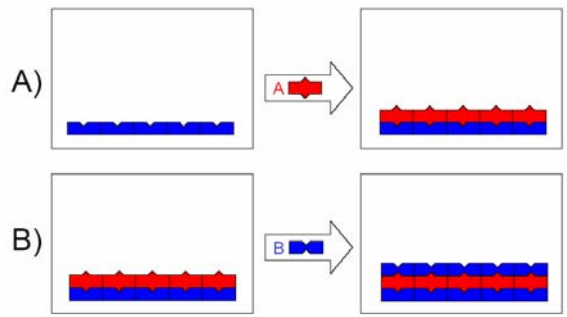
•Impact: **Increased conversion rates** (65% to 75%) and **lower energy consumption** for **bulk organic chemicals production**. ALD catalysts can also be used in fuel cells and for transportation fuels and hydrogen production.

•Market: $12.3 billion in 2010 for world catalyst market

•ALD technology currently used for mass production of Dynamic Random Access Memory (DRAM) chips**.**

"The world catalyst market will reach $12.3 billion in 2010, driven by growing demand in the chemical, polymer and refining industries for more energy efficient processes and products."
Freedonia Group

Atomic Layer Deposition (ALD) precise surface control



Jeffrey	Elam	Argonne
(630) 252-3520	jelam@anl.gov	

Catalyst Manufacturing by Atomic Layer Deposition

•Other Potential Applications:

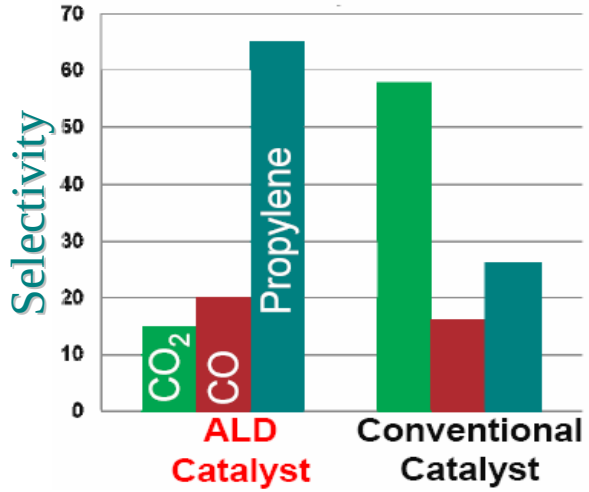
- solid state lighting ($4 billion for high-brightness LEDS in 2007)
- solar cells ($7.6 billion 2004)
- superconducting radio-frequency (SCRF) cavities for international linear collider ($3 billion for cavities)
- membranes for separations ($2.4 billion in USA 2006)

•IP: Argonne has two patent applications and one invention disclosure. Additional patent applications on ALD technology. Technology available for licensing.

•Status: Argonne has demonstrated superior performance at bench scale. Scale-up of catalyst manufacturing is in progress.

- Availability – 3-5 years (est.) to prepare for full implementation into catalyst market.
- Capital Needs - ALD catalyst will retrofit into existing facilities with minor equipment changes.

Atomic Layer Deposition (ALD) precise control



ALD produces 2.4 times more propylene

Jeffrey	Elam	Argonne
(630) 252-3520	jelam@anl.gov	

Multiport Cylinder Dryer for Retrofit and New Installations

- Problem: Current paper drying technology is relatively inefficient and capital intensive.
- Description: Multiport dryer technology improves paper drying through a radically different steam-flow design which substantially increases heat transfer leading to:
  - Dryer production rates boosted 20-50% relative to conventional dryers
  - Energy costs lowered through reduced steam pressures
  - New flexibility with respect to paper/cardboard thickness.
- Impacts: Retrofit of multiport dryer inserts **provides 20-50% increases in productivity** of existing equipment.
  - For installations in new plants, multiports reduce the numbers of dryers (capital) required per application.
  - The savings from reduced capital investment (e.g. fewer drums) would increase ROI on the conventional drying line by up to 7% for the multiport dryer.

Multiport Dryer half-shell showing internal dryer insert.

R&D 100 award winner in 2005.

First Name: Ed	Last Name: Daniels	Argonne
Phone: 630-252-5279	E-mail: edaniels@anl.gov	

Multiport Cylinder Dryer for Retrofit and New Installations (cont.)

- IP: Argonne received a patent for this technology in 2002. The technology is available for licensing.
  - Market Size: up to **30,000 paper dryers in the USA**
  - The technology is potentially applicable to **any rotary surface dryer application** (e.g., paper, plastics, food processing).

- Status: A full-scale (10 feet) insert has been designed for testing scheduled for Sep-Oct. 2007.
  - The multiport dryer is designed as an insert into existing dryer drums and therefore targets both retrofit and new dryer installations.
  - Estimated capital cost based on a full-scale demonstration unit is $10,000 - $15,000 per insert.

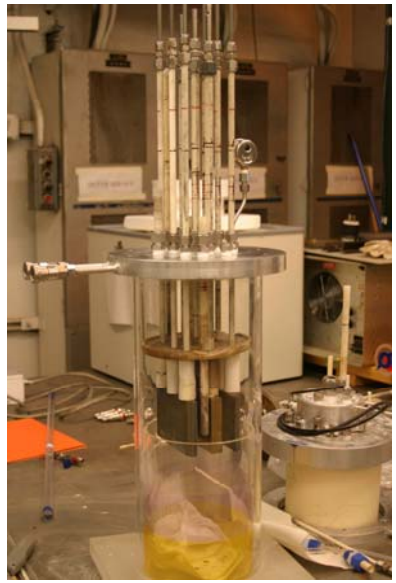
Multiport Dryer half-shell showing internal dryer insert.

R&D 100 award winner in 2005.

First Name: Ed	Last Name: Daniels	Argonne
Phone: 630-252-5279	E-mail: edaniels@anl.gov	

Inert-Anodes for Primary Aluminum Production

- Problem: Primary aluminum production is energy intensive and generates significant quanitities of Greenhouse Gases (resulting from process electricity use and the decomposition of carbon-anodes inherent in conventional cell design)
- Description: A low-temperature electrolyte non-consumable “inert” metallic anode cell design has been developed to replace existing Hall-Heroult cell technology
- Impacts: The new inert-anode cell design reduces energy consumption by up to 25% and eliminates all process CO_2 and PFC emissions.
  - Market opportunity in the U.S. is limited by offshore competition in primary aluminum production. This new technology would have a significant opportunity in growth markets (e.g. Russia and China) that have made commitments to Greenhouse Gas reductions.
- IP: Argonne holds patents on this technology. The technology is available for licensing.
- Status: The process has been confirmed in multiple 100 Amp-100 hour cell trials.
  - Confirmation of cell and anode performance at 1000 Amp-1000 hour trials is needed to enable full-scale design and to confirm sustained cell performance. Estimated cost and time is $ 6 million and 3 years.
  - Capital costs: ~ $1-2 million for cell replacement, $1-2 billion for greenfield site. Estimated 3% reduction in operating costs with an ~2% improvement in ROI for greenfield installation.



100 Amp Inert-anode cell test stand

Commercial-grade aluminum produced from the Argonne inert-anode 100 Amp cell

First Name: Ed	Last Name: Daniels	Argonne
Phone: 630-252-5279	E-mail: edaniels@anl.gov	

Solid State Consolidation, Fabrication, and Joining of Low-Cost Titanium for Industrial Application

- Problem: The high cost and extremely long production lead times of conventionally processed titanium (Vacuum Arc Melted Kroll sponge derived ingot) has limited its application in the industrial sector.
  - Newly developed low-cost titanium powders, produced by innovative chemical reduction methods, have the potential to drastically decrease the cost of titanium from **$40-50/lb to less than $5-$8/lb.**
  - Economical processes to consolidate Ti powders are key to addressing industrial applications.

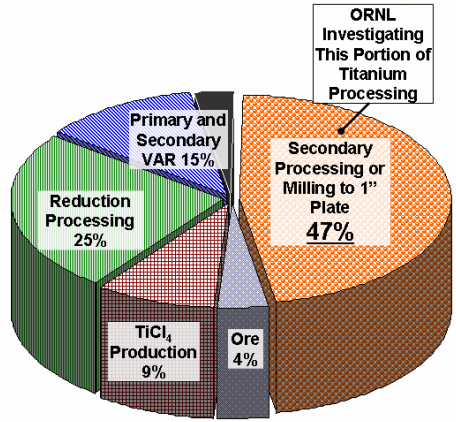
- Description: Titanium is a superior material for many applications due to the highest strength-to-weight ratio of any metal, excellent corrosion resistance, biocompatibility, and good high temperature performance.
  - Solid-state (non-melt) consolidation, fabrication, and joining technologies of Ti powders are being developed to produce low -cost sheet, plate, and near-net-shape complex geometric components for industrial applications.

Industrial Markets for Low Cost Titanium and Ti Alloy

Craig	Blue	ORNL
865-574-4351	blueca@ornl.gov	

Solid State Consolidation, Fabrication, and Joining of Low-Cost Titanium for Industrial Application

- Impact: Efficiencies in solid-state consolidation of powders could reduce the financial and energy cost of production of Ti products by greater than 50%, resulting in consolidated Ti plate at $9-$10/lb.
  - Market: Over 70,000 metric tons per year worldwide. Titanium production projected to triple by 2015 with 50% of growth in Industrial applications.
- IP: ORNL has a patent on Direct Fabrication of Titanium Sheet. Technology is available for licensing.
- Status: ORNL has demonstrated the feasibility of solid state consolidation of low cost titanium powders with wrought properties.
  - Preliminary solid state consolidation of low cost Ti and Ti alloy powders yielded mechanical and chemical properties meeting ASTM standards for wrought titanium.
  - Further development of solid state consolidation Is required to bring low-cost titanium to industry, realize energy savings, and penetrate new markets.
  - 2 years (est.) needed to prepare for full implementation of Ti into industrial market.



Development of Solid State Technologies to Replace Melting and Milling High Costs

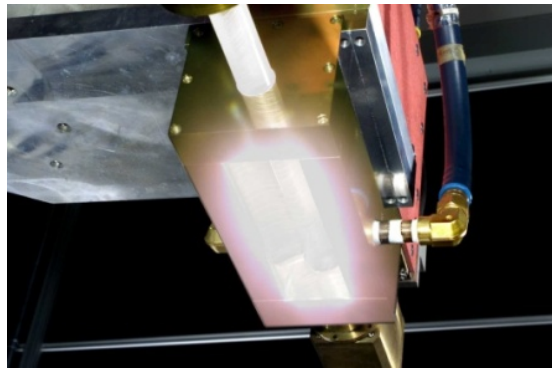
Low-Cost Titanium and Ti Alloy Plate, Bar, and Sheet Produced at ORNL

Craig	Blue	ORNL
865-574-4351	blueca@ornl.gov	

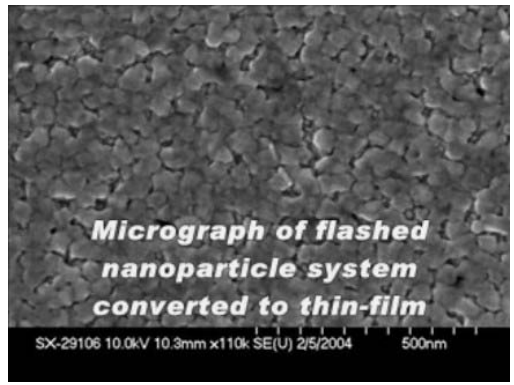
Pulse Thermal Processing (PTP) of Nanoparticle Photovoltaic Materials

- Problem: Thin-film PV material systems, such as copper-indium-gallium-diselenide (CIGS):
  - **Are too costly due to vacuum deposition methods**
  - Have inherent difficulty in controlling composition and performance over large areas leading to reduced performance
  - Goal is to approach solar cell performance observed at lab-scale (19.2 % efficiency) at the full-scale module level. Solar cell efficiencies of 9% are currently the standard.

- Description: CIGS nanoparticles can be fabricated and screen-printed on inexpensive low-temperature polymer substrates and "flashed" utilizing the high density plasma arc-based PTP technology thus achieving **ultimate control of composition and performance over large areas**
  - Advantages include high power density, high heating rates, short processing time and large processing areas.
  - **Other potential applications** include thin-film transistors for flat panel displays, thin-film batteries, LED's for solid state lighting, printed integrated circuits such as Radio Frequency ID tags.



High Density Plasma Arc-Based Technology



0.001 second flash from PTP

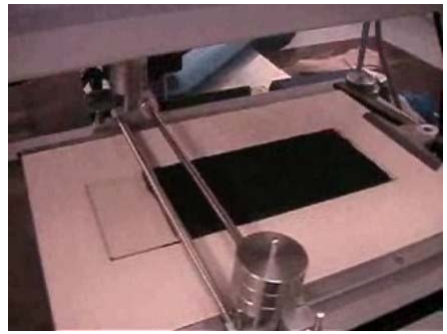
Craig	Blue	ORNL
865-574-4351	blueca@ornl.gov	

Pulse Thermal Processing (PTP) of Nanoparticle Photovoltaic Materials

- Impact: No vacuum deposition systems, thus **tremendous equipment cost savings**
  - **short processing times** leading to high throughput with low-cost polymer substrates
  - **large area compositional control**, resulting in **high performance**.

- IP: ORNL has a patent on Pulse Thermal Processing. Technology is available for licensing.
  - **PV Market:** growing at 30% to 40% per year and will be a $15 Billion market worldwide by 2020.

- Technology Status: Proof-of-principle experiments have been performed at ORNL on a multitude of technology areas
  - Technology is **available as a prototype** rather than an off-the-shelf format
  - Capital Needs: CIGS nanoparticle fabrication and dispersion ink, screen printer, high density plasma arc lamp



Low cost screen printing

Flexible PV

Ronald	Ott	ORNL
(865) 574-5172	ottr@ornl.gov	