SRNL-STI-2015-00522

Savannah River National Laboratory™

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

We put science to work.™

Starting a National Initiative in Chemical Engineering – The RAPID Manufacturing Institute

Bond Calloway

AIChE President

Associate Laboratory Director

Savannah River National Laboratory

Savannah River NUCLEAR SOLUTIONS

FLUOR • NEWPORT NEWS NUCLEAR • HONEYWELL

SRNL Today: Multi-Program National Laboratory

Clean Energy

- Nuclear Fuel Cycle R&D
- Renewable Energy Research
- Grid Research
- Commercial Cyber Security
- Process Intensification
- Smart Manufacturing

National Security

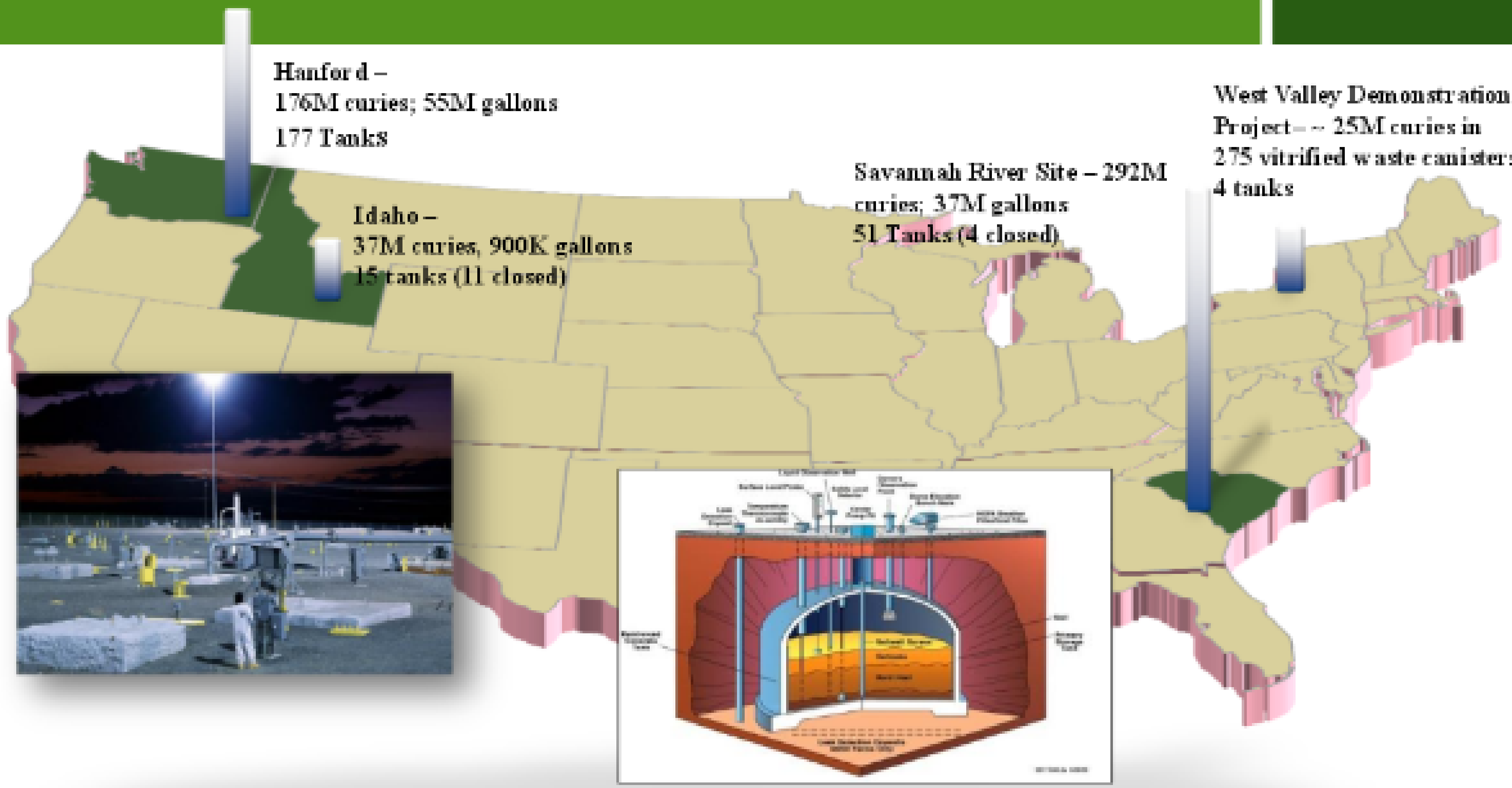
- Nuclear Defense
- Tritium Technology
- Homeland Security
- Nonproliferation
- Nuclear Forensics

Environmental Stewardship

- Waste Treatment
- Materials Stabilization and Disposition
- Remediation and Cleanup
- Assessments and Verification

Mission: Treatment & Disposal of 92 Million Gallons

Waste Processing: Treatment and Disposal of Radioactive Waste
Mission: Treat 92 million gallons (343 million liters)
505 million curies of radioactive tank waste (7.39 x 10^{18} becquerels)

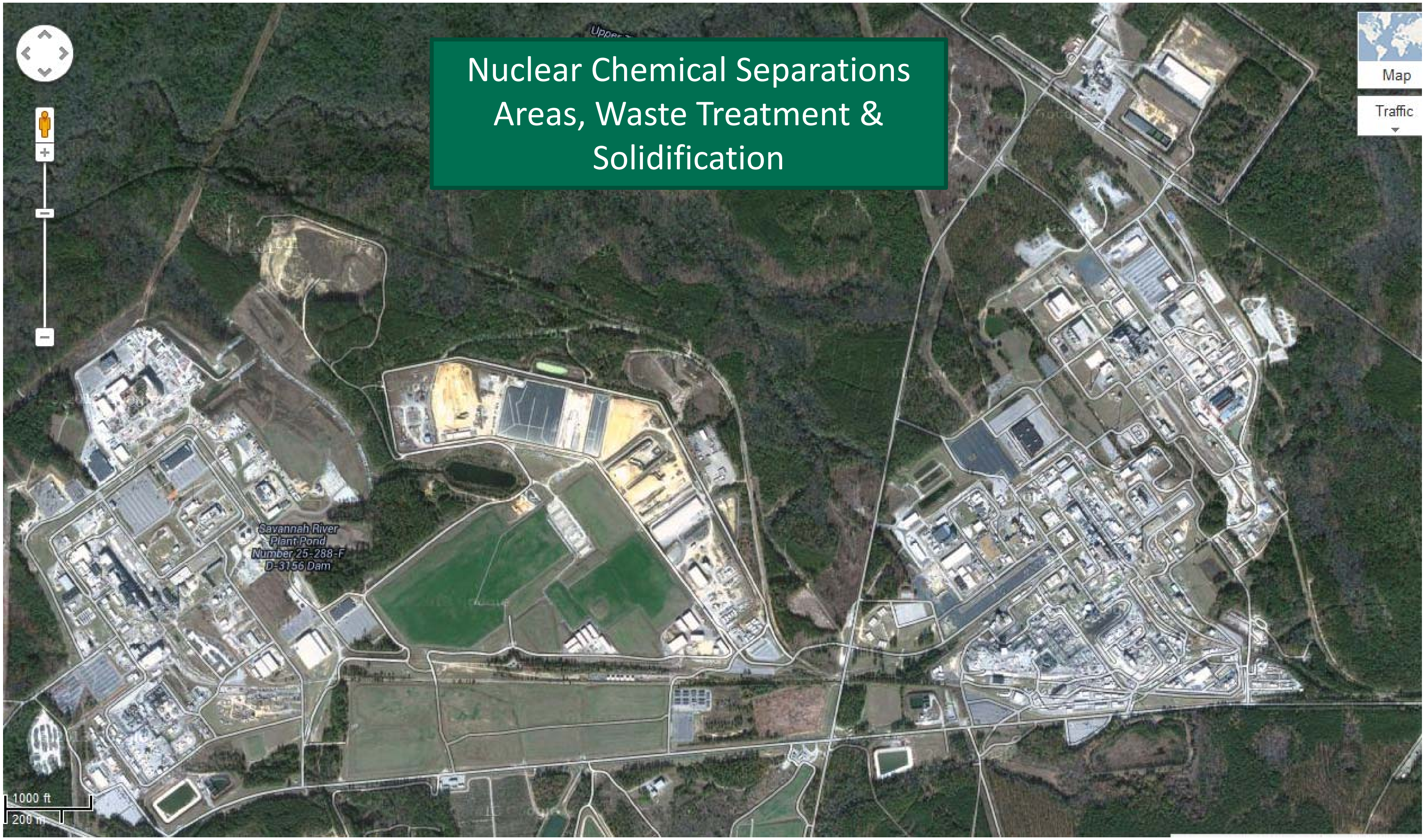


Ken Picha, Dec 3, 2013, http://energy.gov/sites/prod/files/TAB%204.1%20Picha%20EMAB%20Presentation.pdf

How Much is 92 Million Gallons?

375' Diameter, 40' Tall, 32 Million Gallons

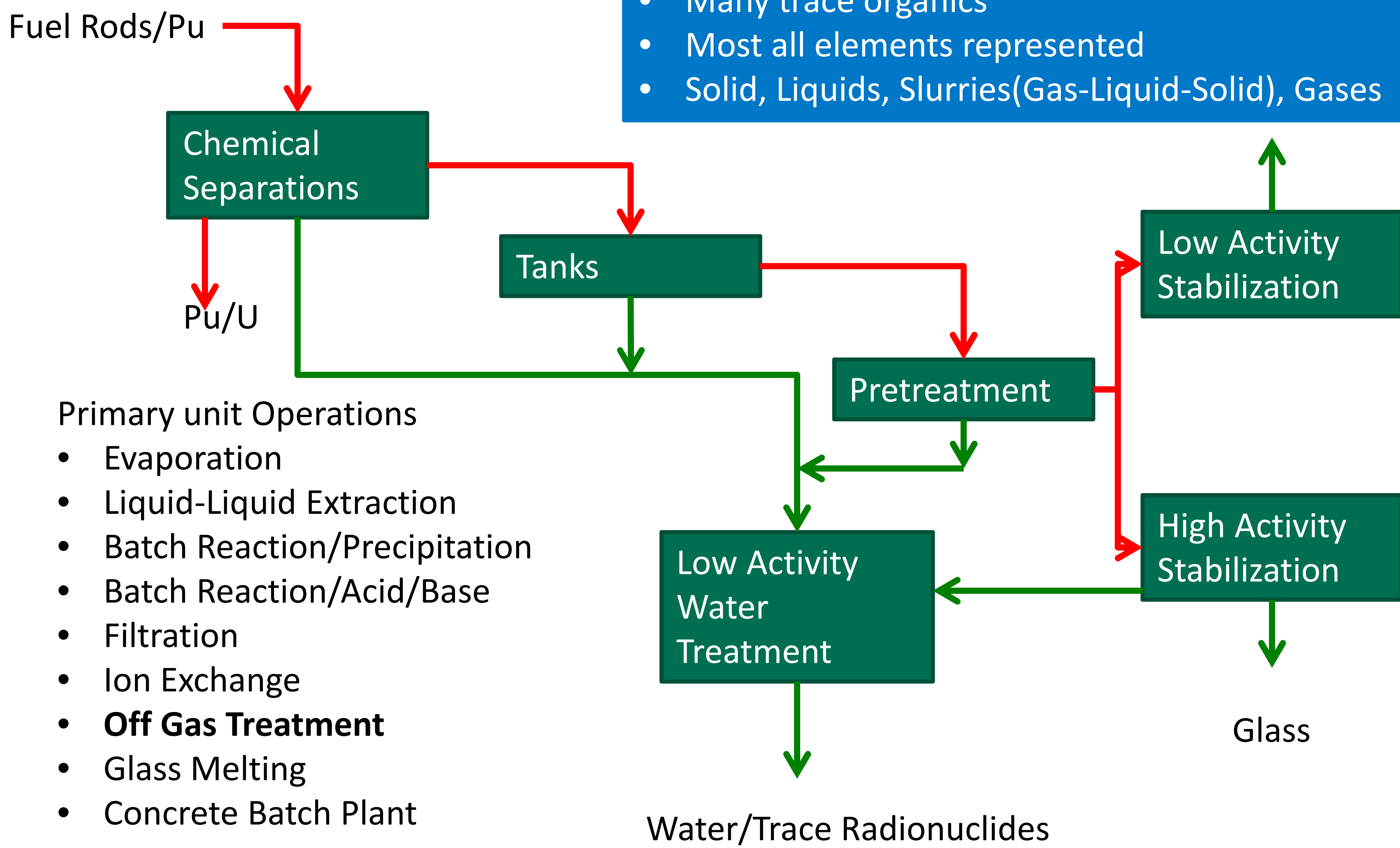
A Large Nuclear Chemical Complex



> 3 Miles

Flowsheet

Chemistry
- Inorganic
- Many trace organics
- Most all elements represented
- Solid, Liquids, Slurries(Gas-Liquid-Solid), Gases



Primary unit Operations
- Evaporation
- Liquid-Liquid Extraction
- Batch Reaction/Precipitation
- Batch Reaction/Acid/Base
- Filtration
- Ion Exchange
- **Off Gas Treatment**
- Glass Melting
- Concrete Batch Plant

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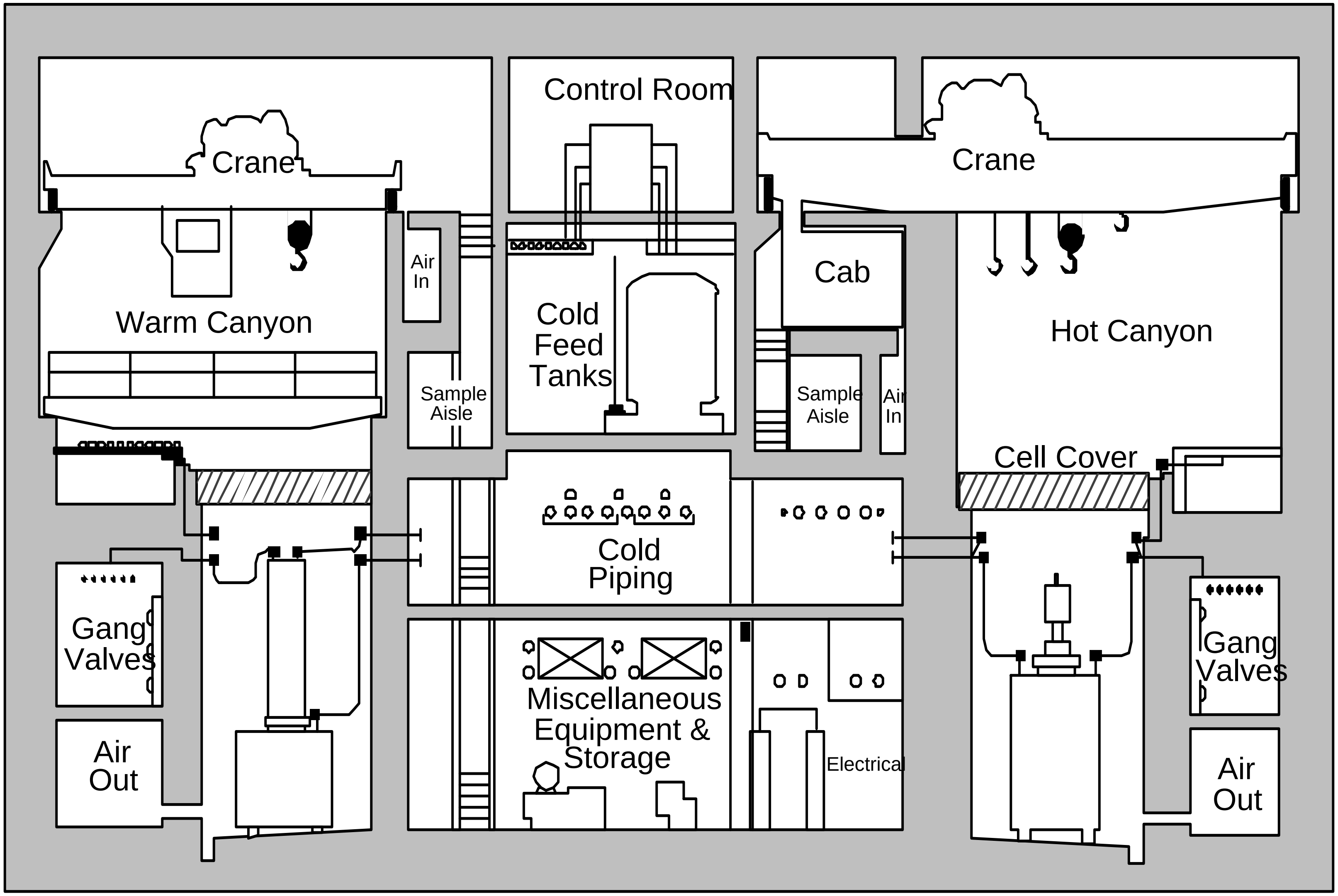
Canyon Cross-Section-Can We Make this Smaller?



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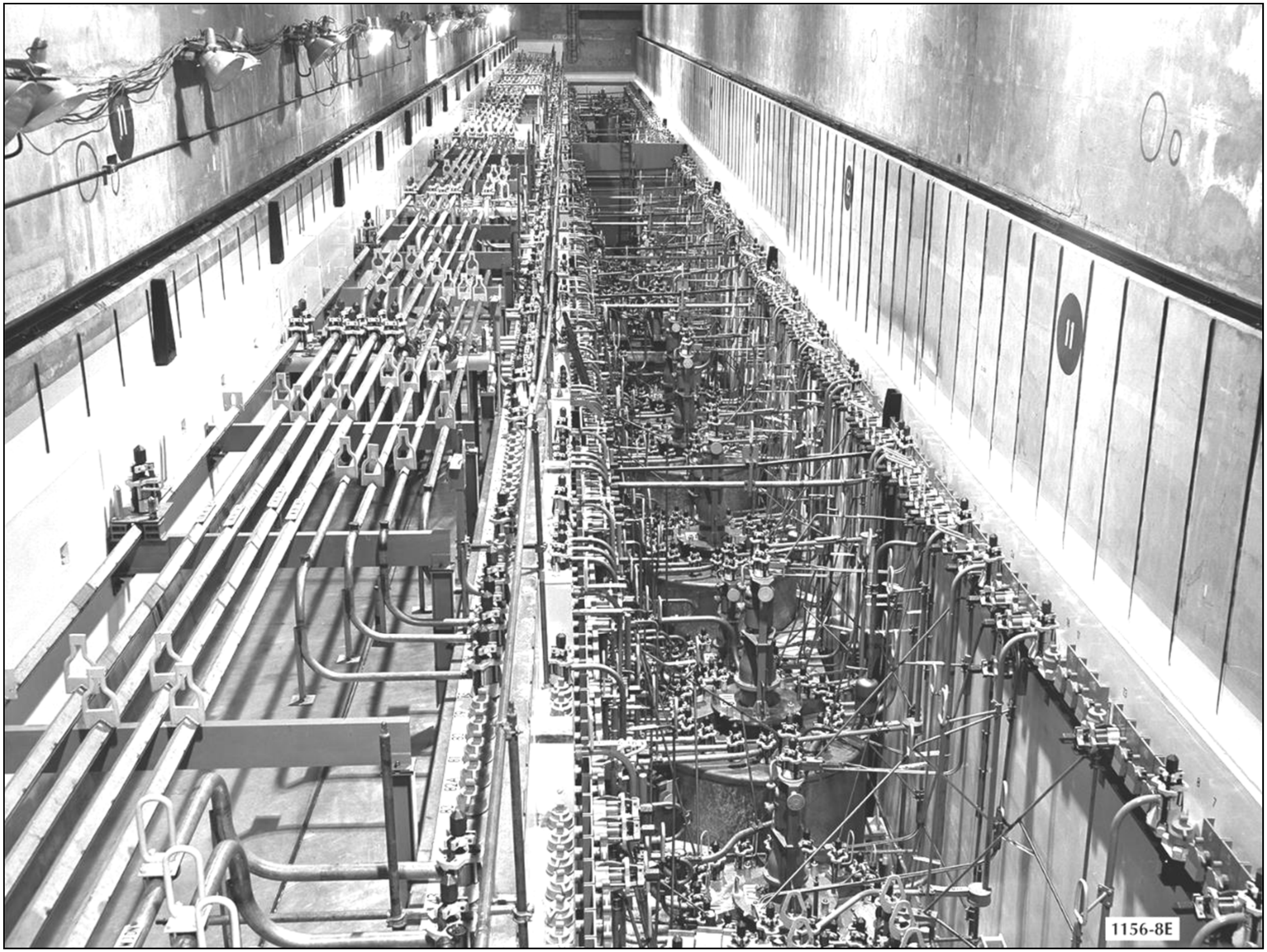
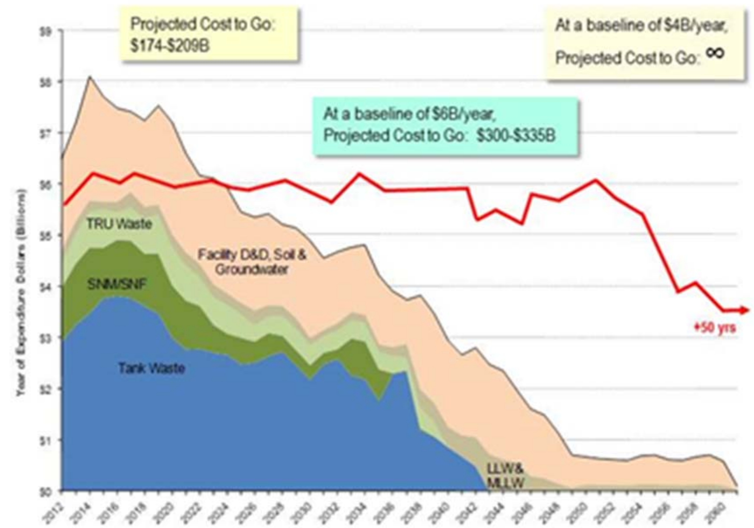
Piping Gallery in Canyon Chemical Separations Facility



Another Multi-Billion Dollar Site Under Construction

Startup 2036 – Price Tag 16.8 Billion as of Dec 2016

Nuclear Waste Clean-up Faces Major Challenges



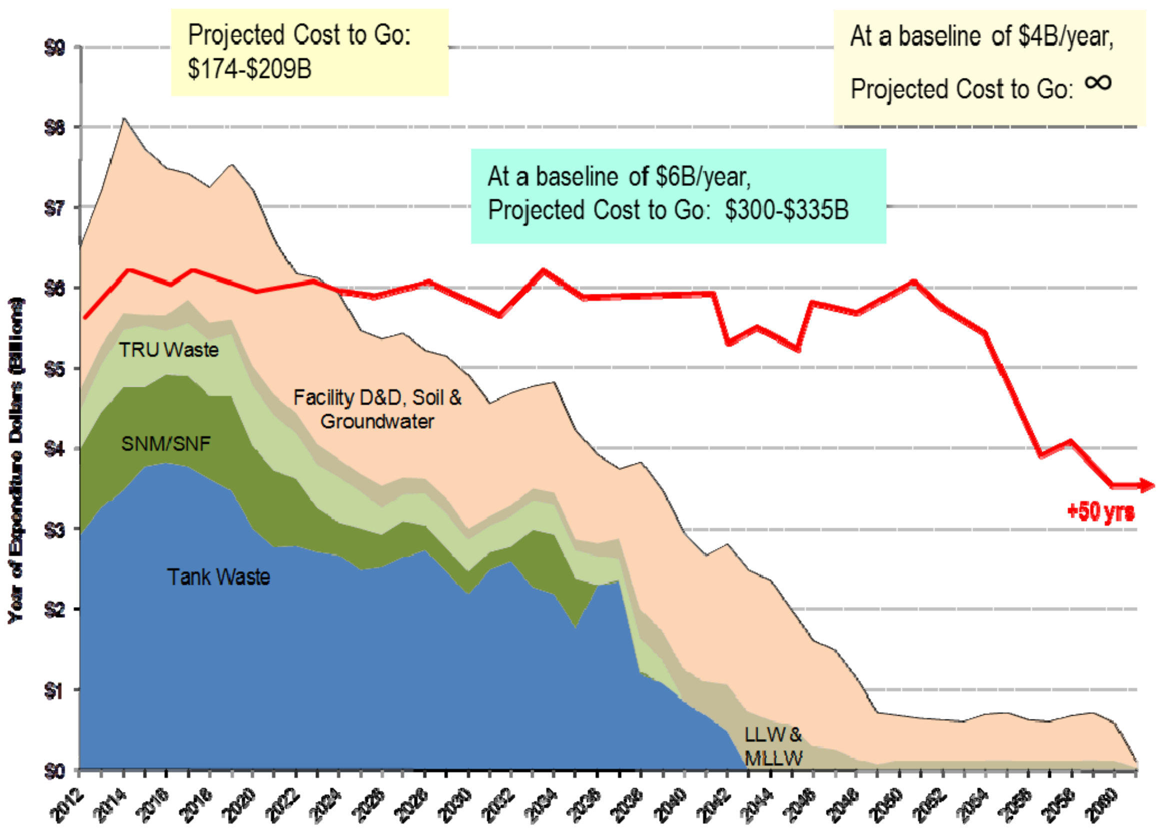
Nuclear Chemical Processing is 30+ Years Behind the Chemical Industry

Old Technology	Old Controls
Bigger is better; Cost ~ Production Capacity$^{2/3}$	Output Based Process Control; Production decisions made offline

Today, EM lifecycle cost is a function of Funding level.

- Meeting baseline regulatory agreements will require unrealistic funding.
- Optimistic funding levels push cleanup schedule past 2070.
- As cleanup schedule extends, maintenance and infrastructure consume increasing fraction of available funds.

Nuclear Waste Cleanup Faces Major Challenges



“Without the application of mature technologies from chemical and manufacturing industries, it is not clear that the cleanup can be completed satisfactorily or at any reasonable cost…”

- SEAB Report of the Task force on Technology Development for Environmental Management December 2014

A New Approach for DOE

Leverage the Concepts of PI and SM to Reinvent Nuclear Chemical Manufacturing

Develop processes that lead to dramatically smaller equipment with

- Improved control of processing kinetics
- Higher selectivity/reduced waste
- Higher energy efficiency
- Reduced capital and lifecycle costs
- Reduced inventory
- Enhanced intrinsic safety
- Fast response times

Bringing Advanced Chemical Manufacturing to DOE Missions

Key Technology	Benefits
Process Intensification	• Reduced Cost • Increased Safety
Additive Manufacturing	• Specialized Tooling • Integrated Waste Forms
Industrial Robotics	• Remove Personnel from Exposure
Smart Manufacturing	• Reduced Cost (reduced sampling) • Integrated Process and Business Models
Virtual Manufacturing & Industrial Simulation	• Enhanced Worker Training, Safety • Improved Work Planning/ Estimates

Reinventing the Approach to DOE Priorities

What If: Flexible/Modular Facilities Replaced Large Processing Plants

SRS SWPF

Capital Cost: $1.4B
Throughput: ~6 Mgal/yr

SRS Interim Salt Processing Facility

Capital Cost: $250M
Throughput: ~4.5 - 5 Mgal/yr
(with Next Gen Solvent)

SRS Small Column Ion Exchange

Capital Cost: $350M (est. for 2 SCIX)
Throughput: ~6 Mgal/yr

Science & Technology Innovation

- Next Generation Solvent
- Centrifugal Contactor
- Rotary Microfilter

SRNL, ORNL, PNNL, INL, ANL
USC, GA, IBC Tech

Science & Technology Innovation

- At-tank Treatment
- Ion Exchange Resin
- Spent Resin Handling

SRNL, ORNL, ANL, Catholic U, Spintek, UOP

PI Example: Rotary Microfilter & Small Column IX

SRNL application of mature technology

- Rotary Microfiltration
- MST treatment
- Ion exchange
- Submersible mixer pumps

Testing designed and executed to reduce technical uncertainties

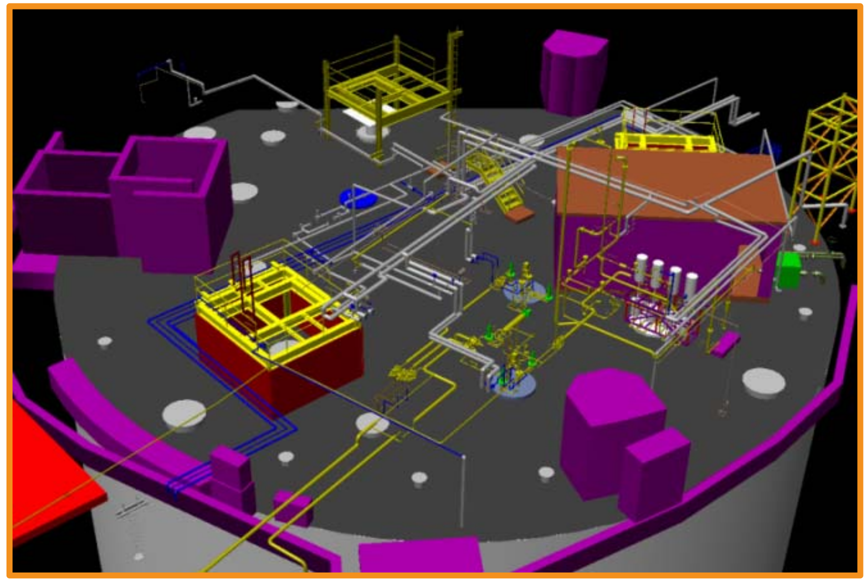
- Rotary microfilter uses high shear to produce high filter flux in small footprint
- Small Column IX eliminates heat loading concerns with large columns
- Low volume of Cs waste in solid form
- Minimized impact to downstream facilities

Deploy at-tank treatment process

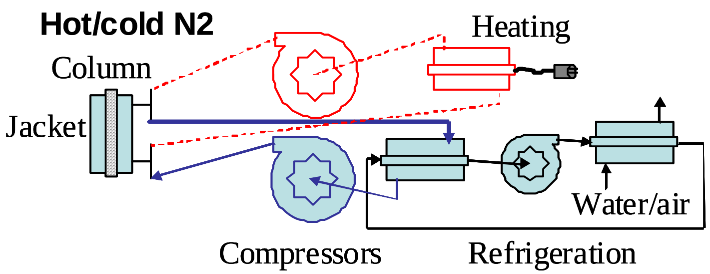
- No new buildings; modular components
- Reduced schedule risk

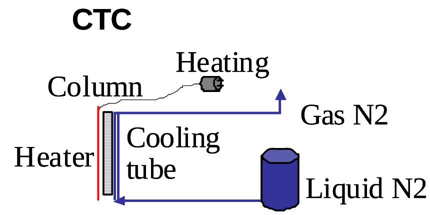
Supplemental salt processing capability

- Potential for six year, $3B lifecycle savings



Process Intensification: Tritium Production





First Generation TCAP (left) versus CTC-TCAP (right, 1/10th footprint)

Scaled Representation of TCAP Development

- Greatly reduced footprint while maintaining throughput

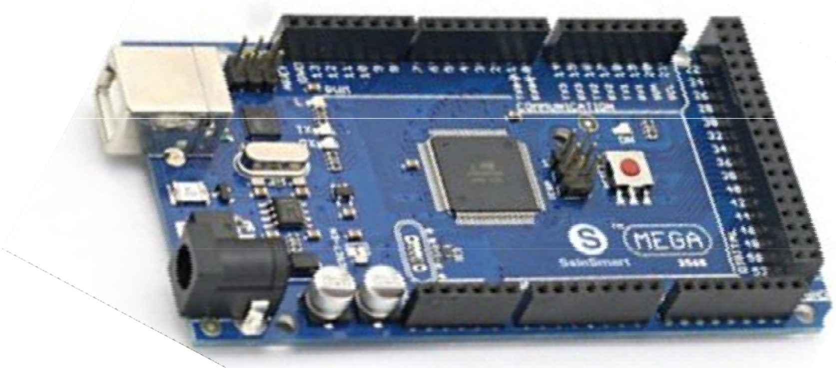
PI Leads to Capital Cost Reduction

SRNL technology & operational improvements – reduce Limited Area by 30%

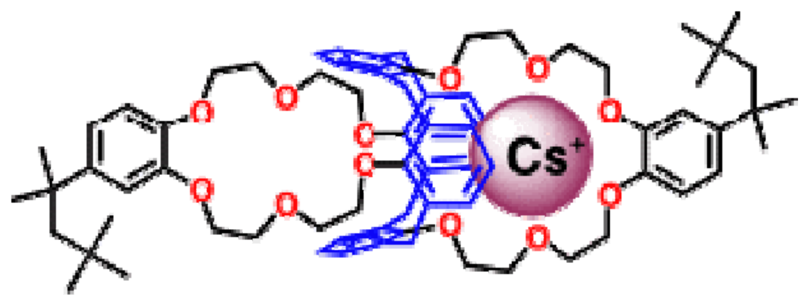
Other Examples

– *Infrastructure Consolidation – Convert distributive control to machine control via embedded microprocessor control – Replace In-building Maintenance*

– *Chemistry Changes – Increase Extraction Efficiency of Solvent*



Replace DCS with Signal Board



Calix[4]arene-bis(t-octylbenzo-crown-6)
"BOB Calix"
(As complexed with Cs^{+} ion)

ORNL

Led to increases in throughput that allowed pilot scale to perform at full scale

Starting a National Conversation

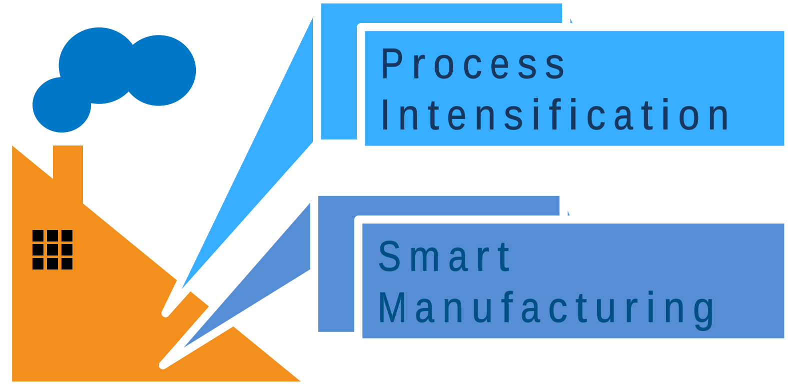
FY13-14

June 2013: SRNL commissioned an internal trade study to develop ideas
>> "Reinvent Nuclear Chemical Engineering."

>> Laboratory Directed Research & Development projects initiated.

May 2014: European Visit to PI Centers of Excellence – *Report Issued*

TWO IDEAS EMERGED FROM STUDY.



FY14-15

April 2014: National Science Foundation funded a Process Intensification Workshop http://processintensification.org/2014. *Led by SRNL, UT-Austin and Rutgers University.*

September 2014: DOE EERE Advanced Manufacturing Office Director became aware of SRNL Efforts

January 2015: Mark Johnson, DOE AMO Director visited SRS and the Clemson eGrid

March 2015: Process Intensification appears in House Energy & Water Bill; *Origin GTI (current partner)*

FY15-16

January-September 2015: Multiple visit to DOE AMO; SRNL's aids in developing a workshop led by DOE AMO entitled "Process Intensification Workshop" http://1.usa.gov/1UykflH

September–January 2016: White Paper developed by SRNL, DOW, UT, PNNL to Make the Business Case for PI; *Much included in the FOA*

February-March: AIChE invited to Two Congressional Briefings on Advanced Manufacturing; SRNL Makes Multiple Visits to AMO

September–April 2016: DOE Consider Four Topics for Manufacturing Institutes – PI Being Considered

April-May 2016: NOI/FOA Announced

Turning PI Into a Reality

Concept Paper Submitted
June 15, 2016

- Hire Grant Writers, Graphic Artists
- Form a Core Team
- Hire a Red Team
- Hire a CEO

SRNL Providing Support To Team

Proposal Due
August 17, 2016

Orals in September

Expected Selection for Negotiations
Before Election

Negotiations
6 Month Period

Road Mapping
6 Month Period

First Hint of Funding
Fall 2017

RAPID

Transforming Process Industries

Process Intensification Solutions for U.S. Manufacturing

1. Manufacturing USA program
2. RAPID Manufacturing Institute
3. A Look Ahead

Introducing: Karen Fletcher, CEO RAPID

Ex. VP of Engineering, DuPont

Manufacturing USA Overview

Vision

U.S. Global leadership in Advanced Manufacturing

Mission

Connecting people, ideas, and technology to solve industry-relevant advanced manufacturing challenges, thereby enhancing industrial competitiveness and economic growth, and strengthening our national security.

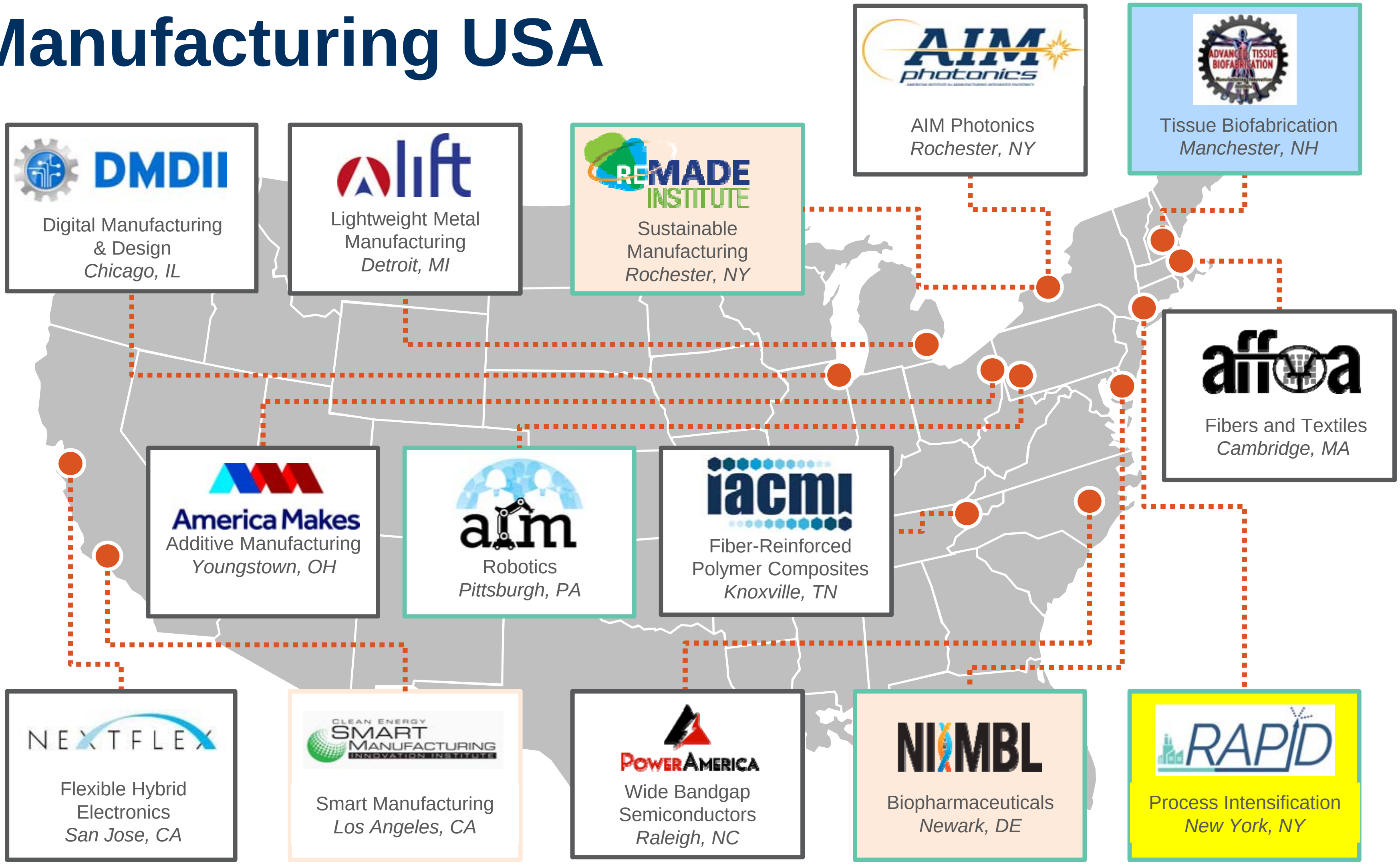
Goals

1. Increase competitiveness
2. Facilitate technology transition
3. Accelerate the manufacturing workforce
4. Ensure stable and sustainable infrastructure

www.ManufacturingUSA.com

The Global Home of Chemical Engineers

Manufacturing USA



RAPID
Transforming Process Industries

RAPID's Industry-Led Vision

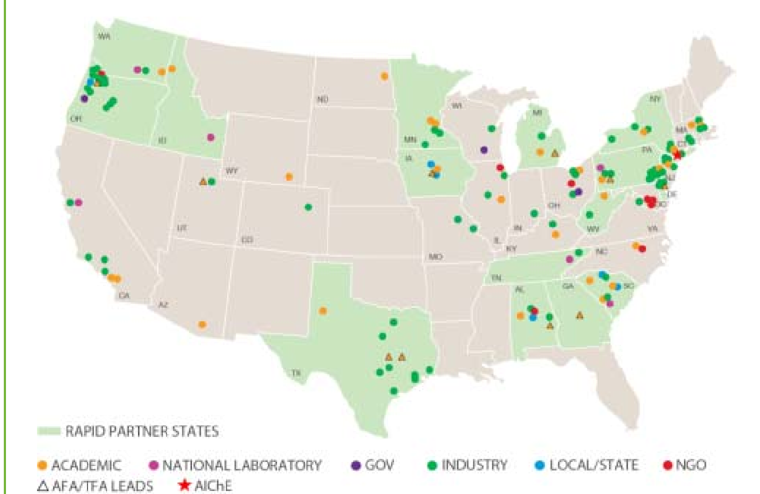
A dynamic network of partners who collectively build a sustainable ***ecosystem*** *that:*

… researches, develops and broadly commercializes new technology for modular chemical process intensification

… delivers dramatic reductions in energy, greenhouse gas, capital and operating cost

… makes U.S. Manufacturing and our workforce more competitive

RAPID's Ecosystem



Industry leaders, researchers, educators, engineers, operators and facilities

RAPID
Transforming Process Industries

Our Mandate

- Lead a national effort to research, develop and demonstrate high-impact modular chemical process intensification solutions for U.S. Manufacturing.
- Actively build RAPID membership through an inclusive and attractive value proposition.
- Leverage $70 million of federal funding with cost share from members.
- Operate the Institute to benefit a wide range of stakeholders.
- Establish an infrastructure that enables access to process intensification resources, tools, expertise, and facilities.
- Bring together private and public entities to co-invest in R&D, commercialization, and deployment of innovative technologies.
- Establish a technical education and workforce development program.

"The goal for these Institutes is to revitalize American manufacturing and support domestic manufacturing competitiveness."

— U.S. DOE

RAPID
Transforming Process Industries

Initial Partners

Industry … Academia … National Labs & Non-Profits

Earth Energy Renewables
CF Tech
Compact Membrane Systems
Full Cycle
BgtL LLC
Dow
Biodico
Fluor
Domtar
Shell
GE
EcoCatalytic Technologies
Southern Company
DuPont
Cummins
ExxonMobil
Praxair
easy energy systems
Arkema
The world is our inspiration
Pall
Xcel Energy
BASF
We create chemistry
Emerson
Solvay
Petron Scientech Inc.
PGE
Roeslein
ATI
enginuity
NatureWorks
Onboard Dynamics, Inc.
United Technologies
Reliance Industries Limited
Corning
Eastman
Saint-Gobain Norpro
NuScale Power
Lubrizol
3DMFG
Automation Solutions
Master your machines
aspentech
CBI
Italmatch Chemicals
CeramTec
IntraMicron
ZeaChem
Kore Infrastructure
Zaiput Flow Technologies
Quest

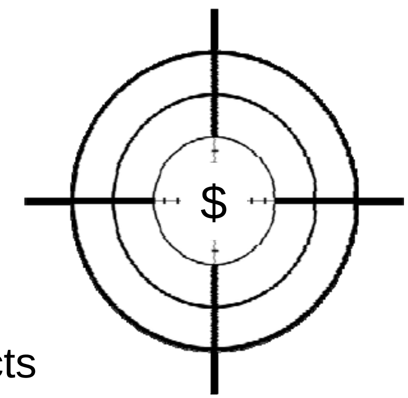
Georgia Tech
Oregon State University
OSU
Texas A&M University
Iowa State
Auburn University
University of Michigan
USC
Texas Tech University
Drexel University
UND
Michigan State University
Clemson University
Ucla
The University of Arizona
WPI
Manhattan College
Texas
NC State University
University of Idaho
College of Engineering
Illinois
West Virginia University
Carnegie Mellon Engineering
University of Louisville
Case Western Reserve University
University of Delaware
University of Pittsburgh
UW
University of South Carolina
University of Kentucky
Alabama
SUNY
Rutgers

RTI International
American Chemistry Council
Agenda 2020
AIChE
GMIC Glass Manufacturing Industry Council
gti Gas Technology Institute
SOCMA Society of Chemical Manufacturers & Affiliates
Southern Research
USFS
Savannah River National Laboratory
Pacific Northwest National Laboratory
Lawrence Livermore National Laboratory
The Ames Laboratory
Idaho National Laboratory
Operated by Battelle Energy Alliance
Oak Ridge National Laboratory
National Energy Technology Laboratory

50 of our 75 companies are shown here

An "Industry-Centric" Institute

- Access to new process intensification technology and tools with the potential for:
  - Lower capital cost
  - Lower operating cost
  - Improved process efficiency
  - Improved energy efficiency
  - Reduced waste
  - Reduced environmental footprint



- Participation in roadmapping workshops with access to finished products
- Leveraged investment in R&D projects that directly address industry challenges
- Access to tools, models, and educational materials
- Networking and collaboration with academia, national labs, supply chain partners

RAPID Value Proposition

RAPID Transforming Process Industries

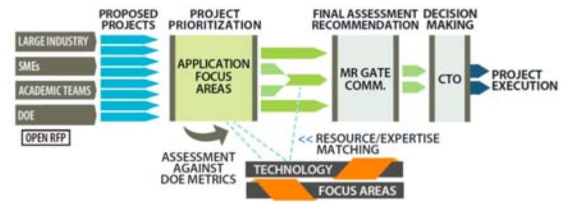
1. Roadmapping & Strategy with Partner input

AIChE

2. Address the Barriers to PI Adoption

- Modeling/Simulation/ Optimization & Control for Existing PI Processes
- Material & Chemistry Intensification for Existing Processes
- Low Energy Separation for Existing Processes
- Module Manufacturing for PI and MCPI
- Modular Decentralized Scale-Out Processing

3. Disciplined / Gated Work Processes



4. Demonstration & Scale-up

5. Deliverables

- Capital Investment/ Commercial Deployment
- Technology
- Technology Solutions
- Standards/ Design Tools/ Design Specs Available
- Work Force Trained

6. Progress toward long-term targets

IMPACT

800,000 Jobs Created

1100 TBtu Energy

82 MT CO_2

1900 Trained/Yr

Design Tools

>120 Industry Partners

7. Feedback, Guidance

10 Years from now

RAPID Outcomes…

- Commercial Successes
- Module Supply Chain
- Project Pipeline
- Workforce Development

Indicators…

Member testimonials

PI-related capital spending

Module production

PI models, tools

RAPID project portfolio

PI conferences

Training tools

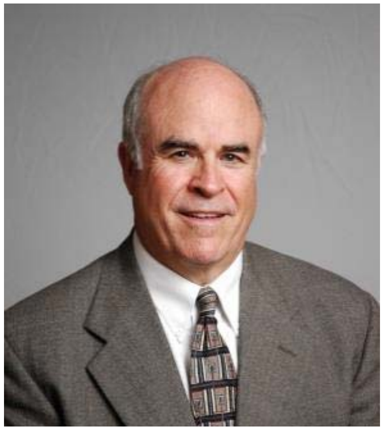
Job creation

RAPID Transforming Process Industries

6 Technical Focus Areas

Chemical & Commodity Processing

- Develop guidelines for integration of novel reaction and separation modules
- Validate design tools for process intensification

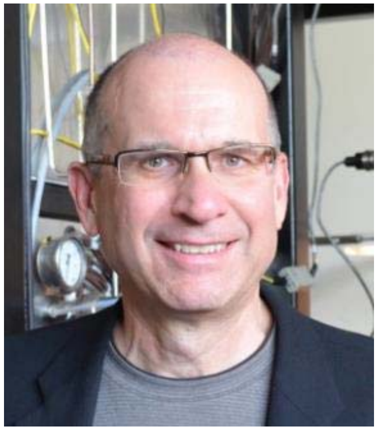


Thomas Edgar
Univ. of Texas

Ramanan Krishnamoorti
Univ. of Houston

Renewable Bioproducts

- Prototype and scale novel bio-conversion processes
- Improve energy & capital efficiency of existing and emerging processes



Robert Brown
Iowa State Univ.

Shri Ramaswamy
Univ. of Minnesota

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Transforming Process Industries

6 Technical Focus Areas

Natural Gas Upgrading

- Maximize impact through transfer of technologies and learnings across industries
- Mature and demonstrate transformational and enabling technologies for gas utilization

Modeling & Simulation

- Develop methods & tools for design, optimization, and intensification across multiple length and time scales
- Establish methods for intensification of dynamic/periodic operations

Michael Matuszewski
Univ. of Pittsburgh

Levi Thompson
Univ. of Michigan

David Sholl
Georgia Tech

Stratos Pistikopoulos
Texas A&M

6 Technical Focus Areas

Intensified Process Fundamentals

- Advance inherently energy efficient separation processes & reaction platforms
- Develop fundamentals for multifunctional modules such as hybrid separation/reaction schemes

Module Manufacturing

- Standardize modules and components to drive demand and capital investment within the supply chain
- Lower the cost of PI equipment using advanced manufacturing technology

Dion G. Vlachos
Univ. of Delaware

James A. Ritter
Univ. of South Carolina

Brian Paul
Oregon State Uni

Ward TeGrotenhuis
Pacific Northwest Nat'l Lab

Facilities and Testbeds

Representative Examples

- Leverage extensive, existing capabilities and capital already invested by our partners
- Key to our RD&D program are testbeds in the areas of module manufacturing, CPI for membranes and reactive distillation, and pulp & paper dewatering
- Access to >10 testbeds and 20 facilities

Austin testbed
University of Texas - Austin

Modules undergoing tests at the
Modular Energy Production Systems Demonstration Facility
Easy Energy Systems—Emmetsburg, IA

Dow's Multipurpose Piloting Facility
Freeport, TX

Education & Workforce Development

- Education & WFD Committee
  - Reports to Technical Advisory Board
  - Committee Members
  - Process Intensification Workforce Development Roadmap (PIWDR)
  - Establish curricula for target audiences:
    - Professionals
    - Undergraduate and graduate students
    - Faculty
    - High school students
  - Start with survey to assess current state

What's Happening NOW?

1. Start-up the Institute
   - Governance
   - Membership drive
   - Website, communications, …

2. Roadmapping
   - One for each Focus Area
   - Strong participation by members, experts
   - Launch in May

3. "Jump Start" projects (4)

4. Project Call for Proposals

Jump Start #1: Chemical and Commodity Processing

Dynamic intensification of the operation of dividing wall columns

Technology Challenge

- Classic paradigm for chemical process control is built on steady state operation - recent theoretical work suggest significant energy savings by considering dynamically controlled process (non-steady state)

Project Outcomes

- Develop theoretical basis for periodic operation of intensified processes & screening criteria to identify candidate technologies
- Experimental proof of concept using dividing wall column (DWC) pilot plant available at UT

Jump Start #2: Natural Gas Upgrading

Adsorptive Nitrogen Rejection from Natural Gas

Technology Challenge

- Nitrogen has been used as an alternative to water in fracturing in unconventional gas – lack of modular gas separation technology leads to >10,000GJ of energy lost to flaring per well

Project Outcomes

- Field demonstration of portable, modular PSA system enabled by breakthrough rate selective adsorbent

Jump Start #3: Renewable Bioproducts

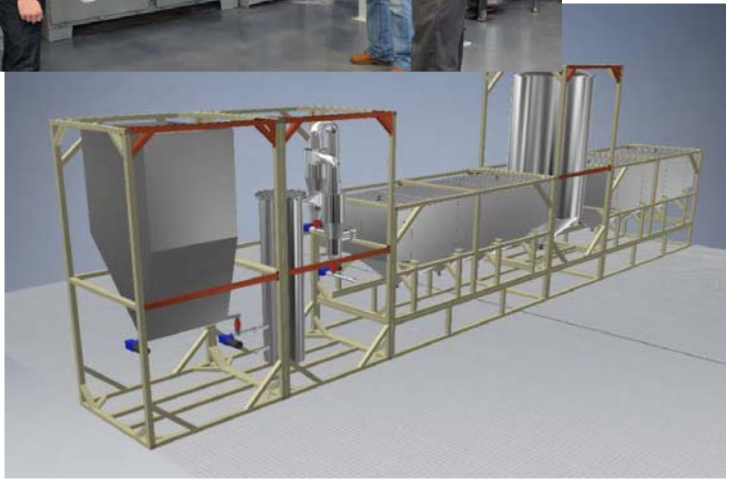
Autothermal pyrolysis of lignocellulose wastes to sugars and other biobased products

Technology Challenge

- Existing technology for conversion of biomass to sugars is carried out at low temperature and long residence time – no ability to use modular technology to address supply chain cost

Project Outcomes

- Demonstrate PI benefits of autothermal pyrolysis to enable modular applications
- Establish Product/co-product yields at pilot scale to feed techno-economic analysis
- Design details provided for commercial scale modular conversion system



Jump Start #4: Modular Manufacturing

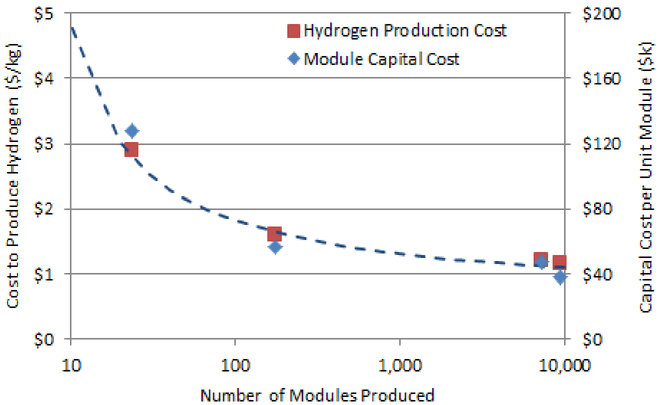
Mfg Supply Chain Development for the Modular Solar-Thermochemical Conversion Platform

Technology Challenge

- Near-term cost savings needed for modularizing and scaling out process chemistries cannot be captured using classical, large-scale methods of manufacturing

Project Outcomes

- Develop novel additive manufacturing techniques and materials that enable modular designs
- Redesign prototype micro- and meso-channel processing technology components to be manufactured using these techniques



Estimated capital and product costs for individual STARS modules as a function of module mass production.

DOE Performance Metrics

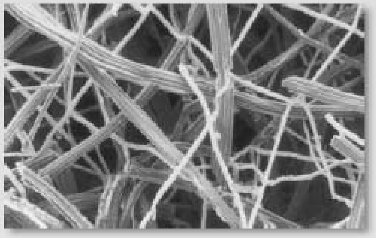
Delivered

- Energy Efficiency
- Energy Productivity improvement
- Intensification in Individual Process Modules
- Cost-Effective Manufacturing of Modules
- Cost Effective Deployment
- Enabling R&D Portfolio
- Industrial Partnerships
- Pathway to Self-Sustainment
- Train the Trainers
- Educate Students
- Annual Planning Process
- Industrial Roadmap
- Emerging Supply Chain
- Diversity of Firms and Individuals in the Eco-System

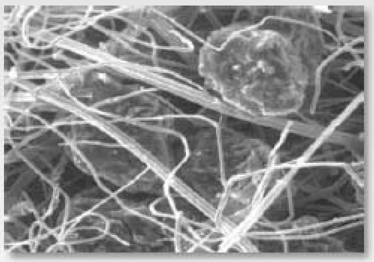
What RAPID Has Already Done!

Microfibrous Media

(Sub Nano to Micro, Meso, Macro and Mega)

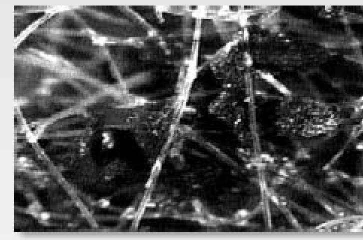


Activated Carbon Fiber and 2 µm Stainless Steel Fibers



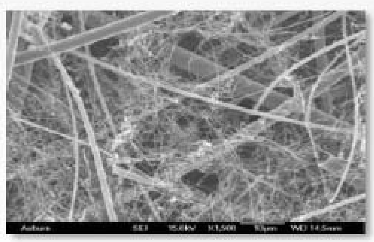
55-85 µm BPL sorbent entrapped in 2,4,8 µm Ni Fibers

2 µm 316L SS Fibers Entrapping Spray Dried TiO_2



100 – 150 µm Activated Carbon
10 – 20 µm Polymer Fibers

100 µm SiO_2 in 2-15 µm Ceramic Fibers



Vapor grown carbon fibers (VGCF) entrapped in 2.4 µm glass-MFM

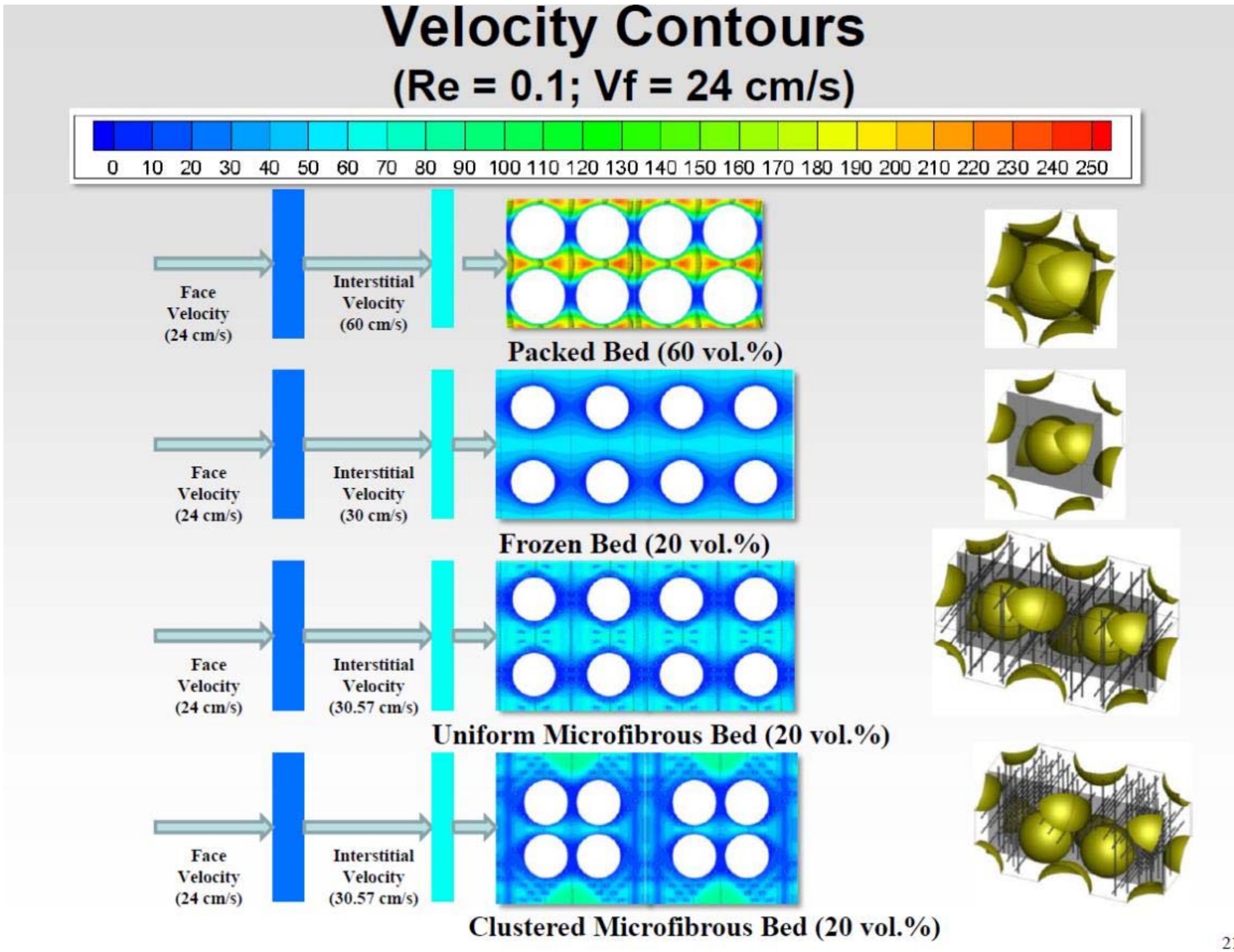
Vapor grown carbon nano-fibers (VGCNF) grown on 1.5 µm Ni-MFM

180-250 mm g-Al_2O_3 entrapped in 8mm SS Fibers

AUBURN UNIVERSITY

Microfibrous Media Application Space
– Gas Separation, Gas Storage, Gas Compression, Ion Exchange, Catalysis

Residence Time Distribution is Optimized



RAPID
Transforming Process Industries

To learn more about RAPID:

www.AICHE.org/RAPID

KareF@aiche.org