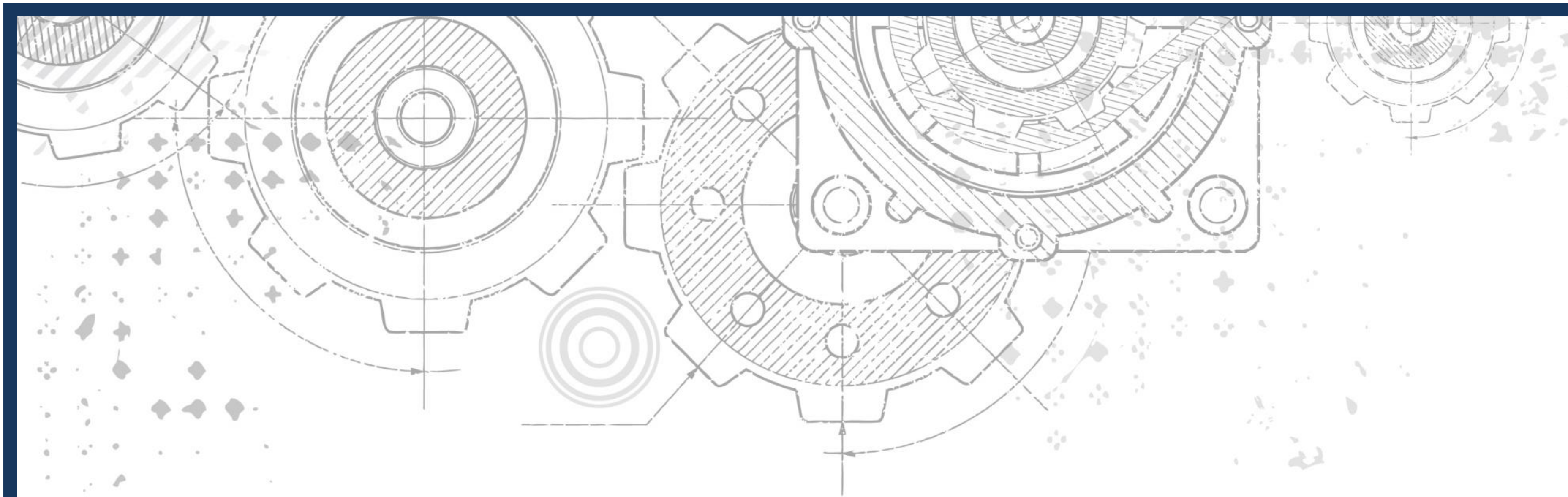
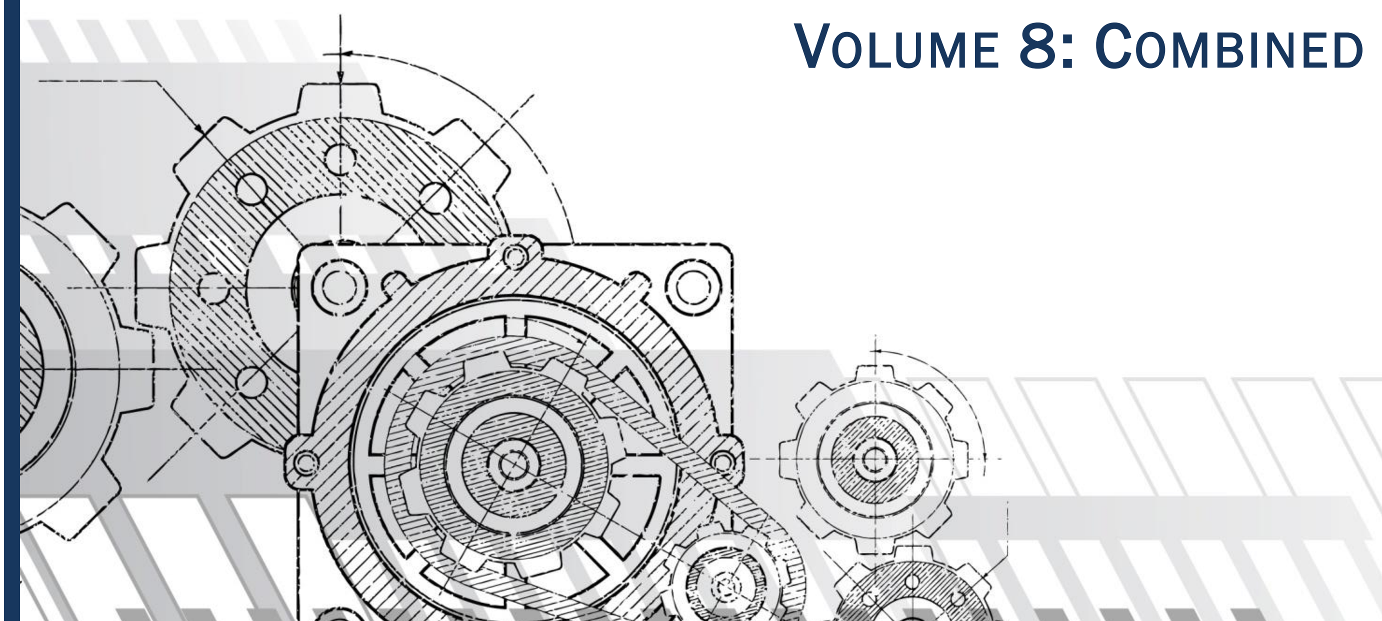


ENERGY EFFICIENCY TECHNOLOGY ROADMAP

VOLUME 8: COMBINED HEAT AND POWER



MARCH 2015

Enhanced PDF Functionality

Functionality of the PDF version of this document has been enhanced in the following ways:

- **Embedded Table of Contents Links:** The Table of Contents has been linked to the appropriate sections of the document.
- **Internal links embedded within the document** to facilitate navigation between sections and "Back to Table of Contents."
- **Control + F:** As always, one can navigate through the document by searching for specific words or phrases by pressing the "Control" and "F" keys simultaneously.

SPECIAL NOTE

This document is one component of the Energy Efficiency Technology Roadmap (EE Roadmap), published by the Bonneville Power Administration (BPA) on behalf of regional stakeholders. For the background and purpose of the full EE Roadmap, a complete list of the project team and contributors, and other explanatory and complementary information, see Volume 1: Introduction & Background.

While BPA has funded and managed the overall development and maturation of this Energy Efficiency Technology Roadmap since 2009, the effort would not have been possible without the active engagement of a diverse array of subject matter experts from organizations and institutions throughout North America. Since the beginning of this roadmapping project, more than 200 participants representing 119 organizations have contributed approximately 5,120 hours and $1,100,000 worth of voluntary input. Their expertise is essential to this project. See Volume 1 for a complete list of contributors.

There is still much collaborative work to be done to improve our understanding of the current energy efficiency technology research landscape but we are making strides in the right direction and we truly appreciate the dedication and contributions of all who have been a part of this important endeavor.

For more information about the Energy Efficiency Technology Roadmap, contact:

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Project Manager
BPA Technology Innovation
jvhillegas@bpa.gov, 503.230.5327

Table of Contents

In This Volume

Additional Content In Volume 1

Introduction to this Volume

This section contains roadmaps in these industrial sector Technology Areas:

- Production
- Resources
- Delivery

Technology Area Definitions

Production

Technologies used to generate heat and power, such as fuel cells, turbines, generators, and heat recovery systems.

Resources

Identifying, sourcing, delivering, and storing fuel used within combined heat and power systems.

Delivery

Storing, moving, and optimizing both heat and energy generated from combined heat and power systems.

Other Sources

The list below is intended to be broadly representative rather than exhaustive and will be updated as new information becomes available.

Selected Sources Regarding Combined Heat and Power Research and Development in the United States

BCS, Incorporated, Waste Heat Recovery: Technology and Opportunities in U.S. Industry. Washington, D.C.: U.S. Department of Energy Industrial Technologies Program, March 2008.

Energy and Environmental Analysis, Inc., “Combined Heat and Power Installation Database,” [last updated May 10, 2010], http://www.eea-inc.com/chpdata/, accessed March 2, 2012.

Heat is Power, http://www.heatispower.org/.

Anna Shipley, Anne Hampson, Bruce Hedman, Patti Garland, and Paul Bautista. Combined Heat and Power: Effective Energy Solutions for a Sustainable Future. ORNL/TM-2008/224. Oak Ridge, Tenn.: Oak Ridge National Laboratory, Dec. 2008.

William Steigelmann and Barry Hinkle, “CHP: The ‘Ugly Duckling’ of Energy Efficiency,” Report 1335, International Energy Program Evaluation Conference, 2009, http://www.cee1.org/eval/db_pdf_es/1335es.pdf.

U.S. Clean Heat and Power Association, http://www.uschpa.org/i4a/pages/index.cfm?pageid=1.

U.S. Clean Heat and Power Association, “National CHP Roadmap: Doubling Combined Heat and Power Capacity in the United States by 2010,” March 2001, http://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_national_roadmap.pdf, accessed March 2, 2012.

U.S. Environmental Protection Agency. “Combined Heat and Power Partnership.” http://www.epa.gov/chp/.

U.S. Department of Energy Northwest Clean Energy Application Center. http://www.chpcenternw.org/.

Combined Heat and Power and Waste Heat Recovery Policy Landscape in the Pacific Northwest

To develop a more nuanced idea of what barrier(s) exist for CHP and waste heat recovery development in the Pacific Northwest, Bonneville Power Administration staff drafted a “Combined Heat and Power / Waste Heat Recovery Policy Landscape Report.” External stakeholders have provided critical commentary to this draft report, and the report is currently being revised

Once completed, the Policy Landscape Report will be paired with Volume 8 of the Energy Efficiency Technology Roadmap to provide regional stakeholders with a much more complete understanding of the technology and policy barriers associated with any future investments in combined heat and power and waste heat recovery systems.

Using the Roadmap

The EE Roadmap is a reference tool designed to be a living, working document. It was not crafted with any expectation that it would be read from beginning to end like a traditional report or narrative. Rather, its design allows for quick reference to technology development research agendas in relation to energy efficiency product and service areas in the residential, commercial, and industrial sectors.

Roadmap content is organized into eight volumes. Volume 1 provides an overall introduction and background, defines key terms and concepts, and guides readers in understanding how roadmap content is organized and interpreted. The remaining volumes contain multiple roadmaps within the respective area:

- Volume 1: Introduction & Background
- Volume 2: Building Design/Envelope
- Volume 3: Lighting
- Volume 4: Electronics
- Volume 5: Heating, Ventilation, and Air Conditioning
- Volume 6: Sensors, Meters, and Energy Management Systems
- Volume 7: Industrial Food Processing
- Volume 8: Combined Heat & Power

In addition to these volumes, there are two ancillary documents to the EE Roadmap:

- Appendix A contains process documents for all of the technology roadmapping workshops held to date, including minutes from each workshop.
- Appendix B contains more information, when available, about existing R&D programs identified in roadmap diagrams.

Disclaimer

Some roadmaps, project summaries, and appendix pages identify specific vendors, commercial products, or proprietary systems and technologies. BPA, its partner institutions, and other stakeholders make these references solely for context; these references do not constitute endorsement on the part of BPA, the Department of Energy, or any stakeholder involved in the creation and refinement of these roadmaps.

Roadmap "Swim Lane" Definitions

Roadmap diagrams are composed of the following four "swim lanes":

Drivers: Critical factors that constrain, enable, or otherwise influence organizational decisions, operations, and strategic plans. These factors can include: existing or pending regulations and standards; the environment; market conditions and projections; consumer behavior and preference; and organizational goals and culture, among others.

Capability Gaps: Barriers or shortcomings that stand in the way of meeting drivers.

Technology Characteristics: Specific technical attributes of a product or service necessary to overcome capability gaps.

R&D Programs: The iterative process undertaken at universities, national laboratories, some businesses, and related organizations to generate new ideas for products and services, develop models and prototypes, evaluate these in laboratory settings, and conduct engineering and production analyses with the goal of delivering the product or service to the marketplace. Within the *Roadmap Portfolio* the generic abbreviation "R&D" is to be understood as including, when appropriate, design, deployment, and demonstration in addition to research and development.

What is the difference between a "Technology Characteristic" and a "Capability Gap?"

A food processing company finds that the machine it currently uses to peel potatoes removes a significant amount of the flesh of the potato. Removing too much of the flesh reduces the yield of each processed potato and this reduced yield means that the company is not getting as much saleable product out of each unit of potatoes. The company must also pay increased costs to dispose of their wastes.

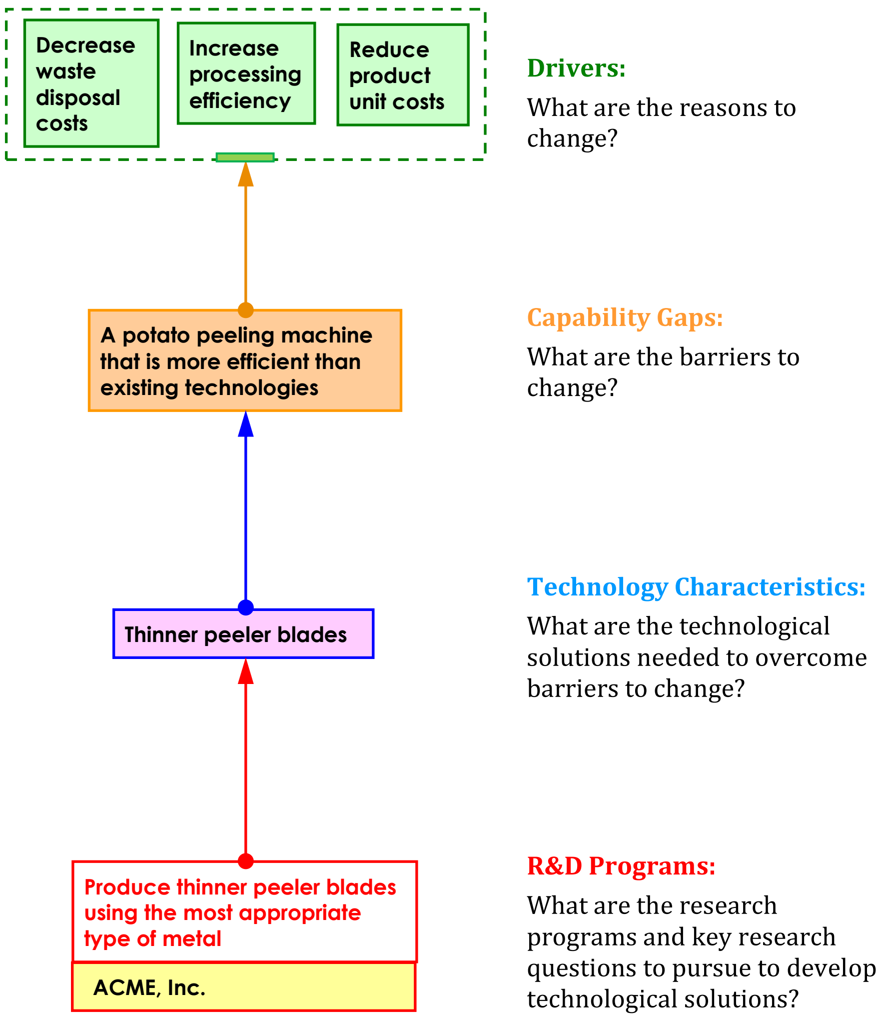
Faced with this situation, the company is facing three Drivers: 1) the desire to increase processing efficiency; 2) the desire to reduce product unit costs; and 3) the desire to reduce waste disposal costs.

Motivated by these drivers, company officials are seeking a solution that will improve the yield of their potato peeling machine. This is their Capability Gap: A peeling machine that is more efficient than existing technology.

Company officials take their request to their engineering team and ask them to develop a solution that will overcome the capability gap and, thereby, meet the three drivers. The engineering team applies their technical expertise to suggest that if they were to reduce the thickness of the peeler cutting blade they would be able to meet the requirements and overcome the capability gap. Thus the engineers have established a Technology Characteristic.

The engineers' next step is to commence an R&D Program in which they investigate the kinds of metal they could use to create thinner blades and then test these blades.

The diagram to the right illustrates this example:



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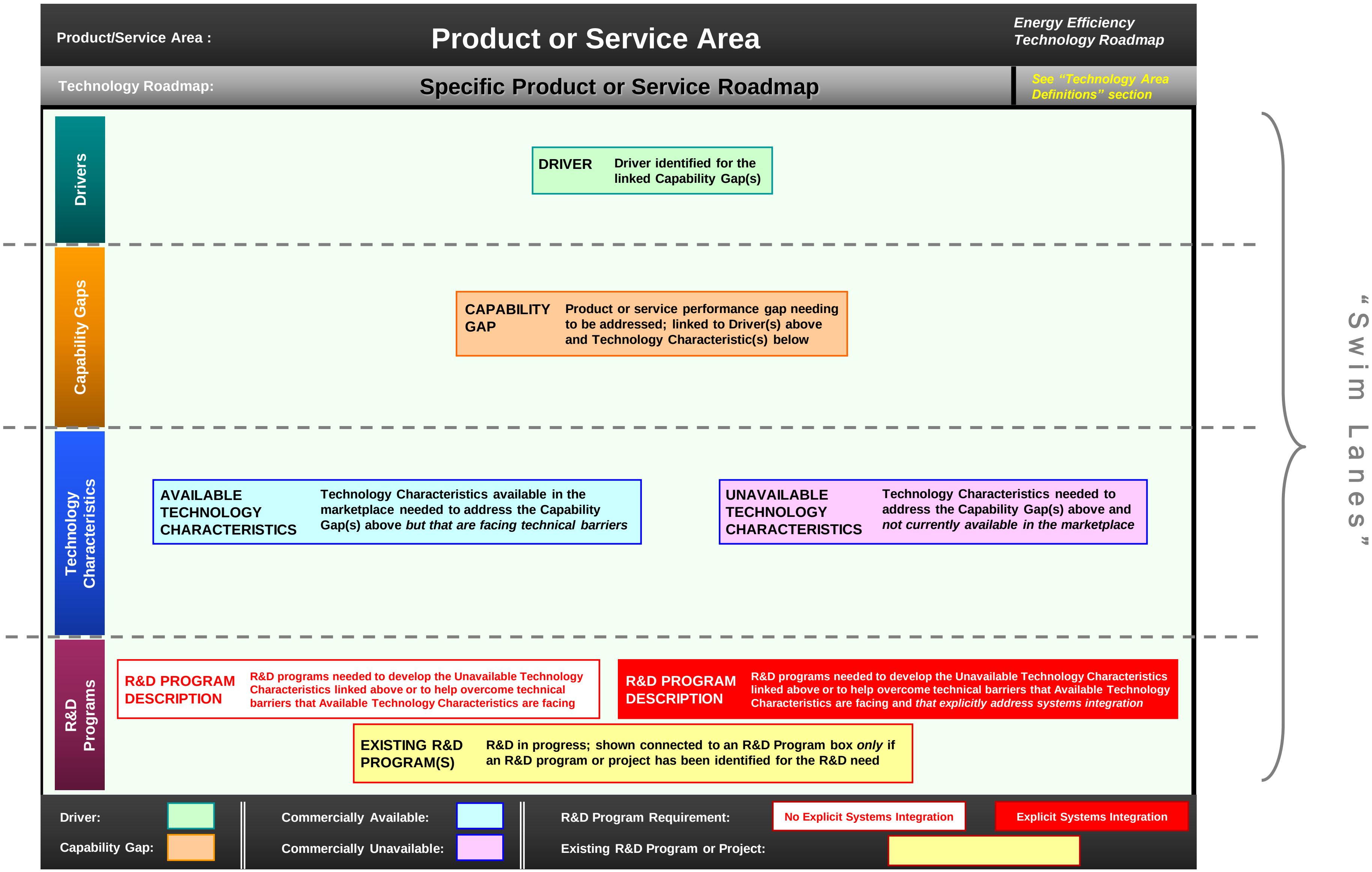
Roadmap Diagram Key



R&D Program Summaries Key

R&D Program Title. Brief summary of R&D program needed to develop the associated Unavailable Technology Characteristics or to help overcome technical barriers that Available Technology Characteristics are facing.

Existing research: Institution(s) listed where R&D program(s) are ongoing.

- Brief descriptive summaries of each institution's R&D program that may include, where applicable, hyperlinks to web pages and/or reference to further program details in Appendix B of the *National Energy Efficiency Technology Roadmap Portfolio*.

Key research questions:

1. One or more research questions that subject matter experts have identified as among the key questions and topic areas to pursue within the R&D program or project; numbers provided for identification only and do not imply prioritization.

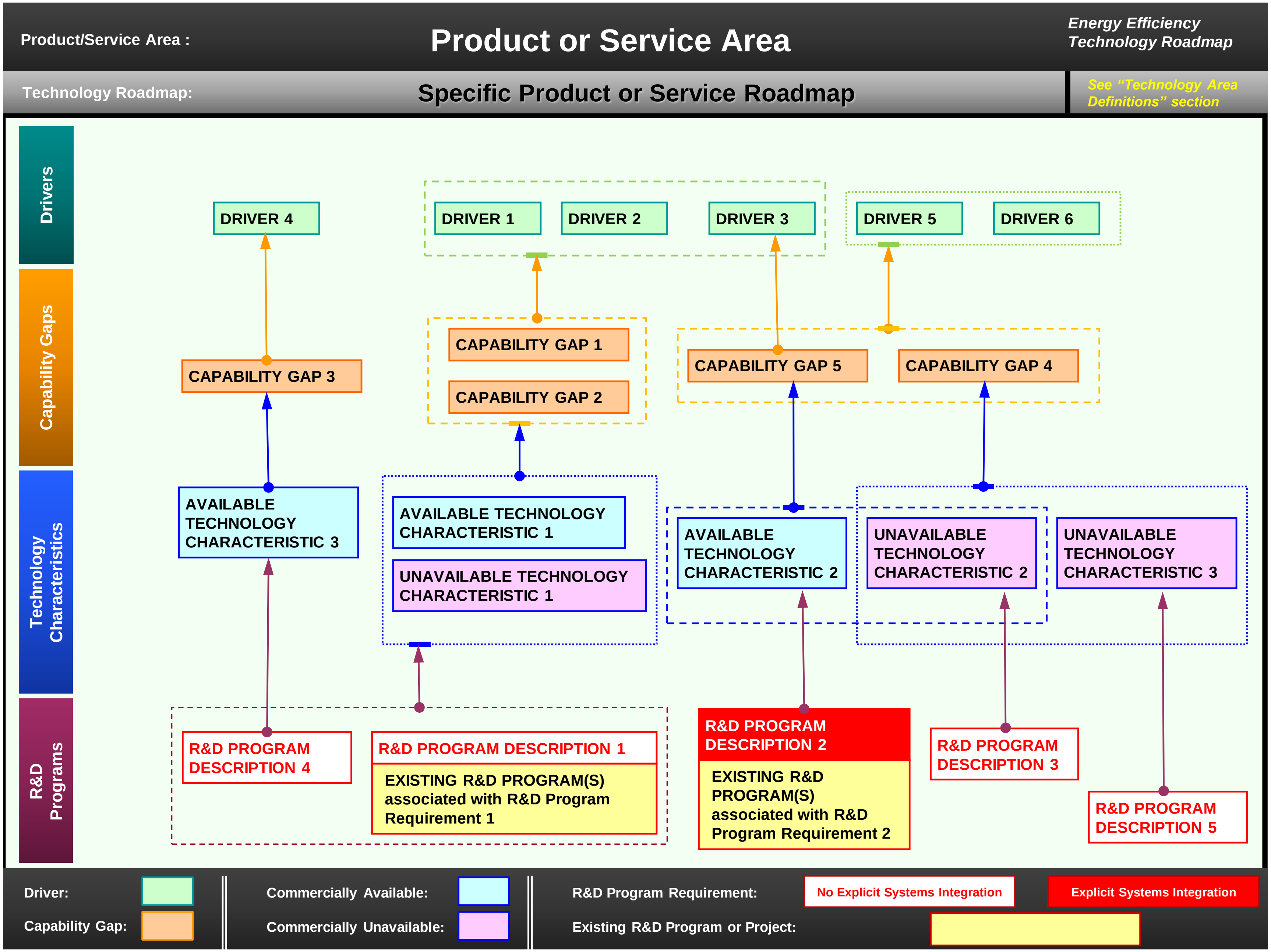
R&D Program Title. Brief summary of R&D program needed to develop the associated Unavailable Technology Characteristics or to help overcome technical barriers that Available Technology Characteristics are facing.

Existing research: None identified. *[R&D program titles that do not have an associated yellow box indicating "Existing R&D Program or Project," by definition, are not underway.]*

Key research questions:

1. One or more research questions that subject matter experts have identified as among the key questions and topic areas to pursue within the R&D program or project; numbers provided for identification only and do not imply prioritization.

How to Interpret Roadmap Pages



The diagram above represents a typical EE Roadmap page. The most straightforward way to interpret portfolio pages is from the R&D Programs “swim lane” at the bottom up through the Technology Characteristics, Capability Gaps, and Drivers swim lanes.

	Arrows connect individual or groups of boxes in swim lanes to identify critical connections between them.
	Dotted and dashed lines indicate that two or more elements in a swim lane are associated and linked either to another element (or group of elements) in the swim lane above and/or below.
	Short, thick solid lines indicate that the arrow is connecting to the dotted or dashed line surrounding two or more boxes.

Thus, in the diagram on the preceding page, the red arrow connects R&D Program Description 4 (at bottom left) to Available Technology Characteristic 3; the blue arrow connects Available Technology Characteristic 3 to Capability Gap 3; and the orange arrow connects Capability Gap 3 to Driver 4. This means that R&D Program Description 4 helps meet Driver 4. Expressed in another way, meeting the requirements of Driver 4 is a rationale for engaging in R&D Program Description 4.

For purposes of illustration some of the other associations to be drawn from the diagram above are explained below. The following abbreviations are used in the examples:

- R&D = R&D Program Description
- ATC = Available Technology Characteristic
- UTC = Unavailable Technology Characteristic
- CG = Capability Gap
- D = Driver

R&D 1 and R&D 4 linked to D 1, D 2, and D 3

R&D 1 and R&D 4 are associated by the surrounding dashed box because they both contribute directly to UTC 1 and ATC 1. This is shown by the red arrow from R&D 1 and R&D 4 to the dotted blue box surrounding UTC 1 and ATC 1.

Both of these technology characteristics, in turn, are associated with CG 1 and CG 2, and both of these capability gaps are linked to D 1, D 2, and D 3.

R&D 3 linked to D 3, D 5, and D 6

R&D 3 is linked to UTC 2, as the red arrow indicates, but *not* to ATC 2 or UTC 3 because the red arrow links directly to the UTC 2 box and not the blue dashed or dotted lines.

UTC 2 is linked to both CG 4 and CG 5 in the following ways: first, the blue dotted box associates both UTC 2 and UTC 3 and these together are linked to CG 4 by a blue arrow; next, the blue dashed box associates both UTC 2 and ATC 2 and these are linked by a blue arrow to CG 5.

CG 4 and CG 5 are associated with one another as indicated by the dashed orange box surrounding them and an orange arrow links both capability gaps to D 5 and D 6.

Though CG 4 and CG 5 are associated in their linkage to D 5 and D 6, CG 5 independently is linked to D 3, as the orange arrow connecting CG 5 and D 3 indicates.

R&D 2 linked to D 3

A red arrow links R&D 2 with ATC 2. R&D 2 is identified with a red-filled box, denoting that this research addresses a need for an integrated systems approach.

ATC 2 and UTC 2 are associated as is shown by the blue dashed box surrounding them. The blue arrow from this box connects to CG 5.

An orange arrow links CG 5 to D 3 but *not* to D 1 and D 2. These three drivers are associated with one another but only in terms of their linkage to CG 1 and CG 2, not in terms of their linkage to CG 5.

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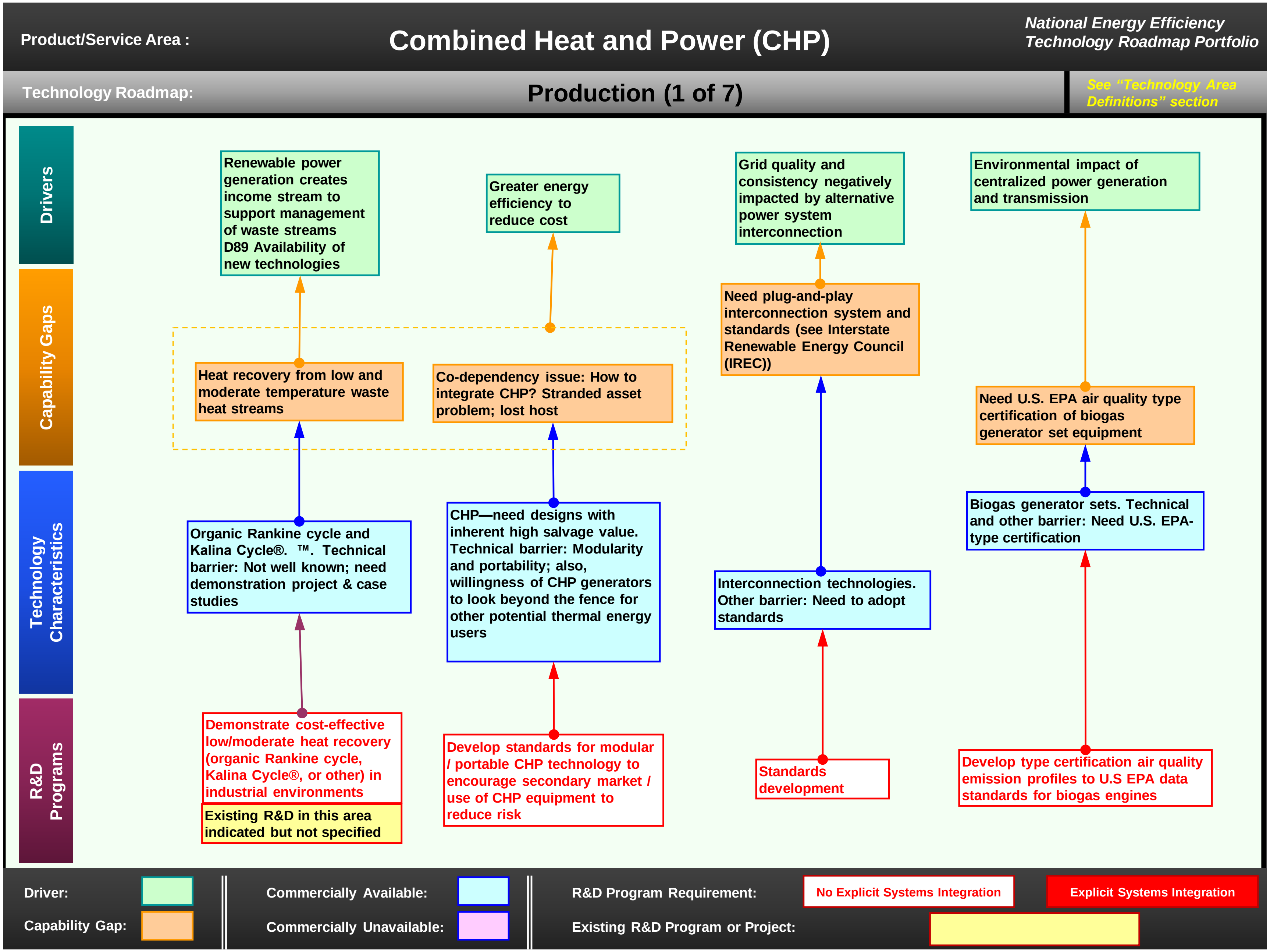

Product/Service Area :
Combined Heat and Power (CHP)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Production (1 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Renewable power generation creates income stream to support management of waste streams D89 Availability of new technologies
Greater energy efficiency to reduce cost
Grid quality and consistency negatively impacted by alternative power system interconnection
Environmental impact of centralized power generation and transmission
Heat recovery from low and moderate temperature waste heat streams
Co-dependency issue: How to integrate CHP? Stranded asset problem; lost host
Need plug-and-play interconnection system and standards (see Interstate Renewable Energy Council (IREC))
Need U.S. EPA air quality type certification of biogas generator set equipment
Organic Rankine cycle and Kalina Cycle®. ™. Technical barrier: Not well known; need demonstration project & case studies
CHP—need designs with inherent high salvage value. Technical barrier: Modularity and portability; also, willingness of CHP generators to look beyond the fence for other potential thermal energy users
Interconnection technologies. Other barrier: Need to adopt standards
Biogas generator sets. Technical and other barrier: Need U.S. EPA-type certification
Demonstrate cost-effective low/moderate heat recovery (organic Rankine cycle, Kalina Cycle®, or other) in industrial environments
Existing R&D in this area indicated but not specified
Develop standards for modular / portable CHP technology to encourage secondary market / use of CHP equipment to reduce risk
Standards development
Develop type certification air quality emission profiles to U.S EPA data standards for biogas engines
Driver:
Capability Gap:
Commercially Available:
Commercially Unavailable:
R&D Program Requirement:
No Explicit Systems Integration
Explicit Systems Integration
Existing R&D Program or Project:

R&D Program Summaries

Demonstrate cost-effective low/moderate heat recovery (organic Rankine cycle, Kalina Cycle®, or other) in industrial environments.
(Summary not yet provided.)

Existing research: As of March 2012 roadmapping workshop participants indicated that there was ongoing R&D in this but did not specify where the R&D was being done.

Key research questions:

1. Questions not yet specified

Develop standards for modular/portable CHP technology to encourage secondary market/use of CHP equipment to reduce risk. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Standards development. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop type certification air quality emission profiles to U.S EPA data standards for biogas engines. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Back to Table of Contents

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Production (2 of 7)**

See "Technology Area Definitions" section

Drivers

- Renewable power generation creates income stream to support management of waste streams
- Availability of new technologies
- Greater energy efficiency to reduce cost

Capability Gaps

- Very high temperature in alpha type engines reduces durability of piston seals. For e.g, Stirling Danmark requires 2 week service every 6 months
- Direct electric power conversion from heat

Technology Characteristics

- Stirling Danmark has commercial scale Stirling projects fueled by biogas in Denmark. Stirling Engine has solar dish application operational since 2010. WhisperGen's MicroCHP stirling engines use natural gas. Challenge is applying to biomass fuel source in U.S.
- Material testing for Stirling engine piston; redesign of Stirling thermocouple/engine design (Stirling Biopower)
- Free piston Stirling engine design is in pilot-phase by Infinia. Bosch free piston design in development
- Direct conversion of heat to electric power
- Thermal equivalent to photovoltaic cells; heat recovery modules that generate electrical power directly from waste heat stream (liquid and gas)

R&D Programs

- Redesign materials for piston rings and thermocouple probes; research and development ongoing at Stirling Biopower and Stirling Danmark
  - Stirling Biopower and Stirling Danmark
- Develop and demonstrate Stirling engine designs that avoid the piston seal problem of the alpha design. Free piston and beta designs are example alternatives
  - R&D institutions not identified
- Advanced Thermoelectric Materials for Efficient Waste Heat Recovery
  - U.S. DOE / PPG Industries / PNNL
- More efficient, compact, and long-lasting thermoelectric materials used in batteries
  - Marlow Industries
- Research to result in commercial materials & systems for direct conversion of thermal energy to electrical energy
  - Existing R&D in this area indicated but not specified

Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Advanced Thermoelectric Materials for Efficient Waste Heat Recovery. (Summary not yet provided.)

Existing research: See U.S. DOE / PPG Industries / Pacific Northwest National Laboratory study, "Advanced Thermoelectric Materials for Efficient Waste Heat Recovery in Process Industries" (http://www1.eere.energy.gov/industry/imf/pdfs/14cps_16947_advanced_thermoelectric_materials.pdf).

Key research questions:

1. Questions not yet specified

Develop and demonstrate Stirling engine designs that avoid the piston seal problem of the alpha design. Free piston and beta designs are example alternatives

Existing research: Workshop participants indicated ongoing research in this area but specific institutions not identified.

Key research questions:

1. Questions not yet specified

More efficient, compact, and long-lasting thermoelectric materials used in batteries. (Summary not yet provided.)

Existing research: R&D ongoing at Marlow Industries (http://www.marlow.com/resources/future-concepts/power-generators-page2.html)..

Key research questions:

1. Questions not yet specified

Redesign materials for piston rings and thermocouple probes. (Summary not yet provided.)

Existing research: R&D ongoing at Stirling Biopower (www.stirlingbiopower.com/) and Stirling Danmark (www.stirling.dk).

Key research questions:

1. Questions not yet specified

Research to result in commercial materials & systems for direct conversion of thermal energy to electrical energy. (Summary not yet provided.)

Existing research: As of March 2012 roadmapping workshop participants indicated that there was ongoing R&D in this but did not specify where the R&D was being done.

Key research questions:

1. Questions not yet specified

Product/Service Area :

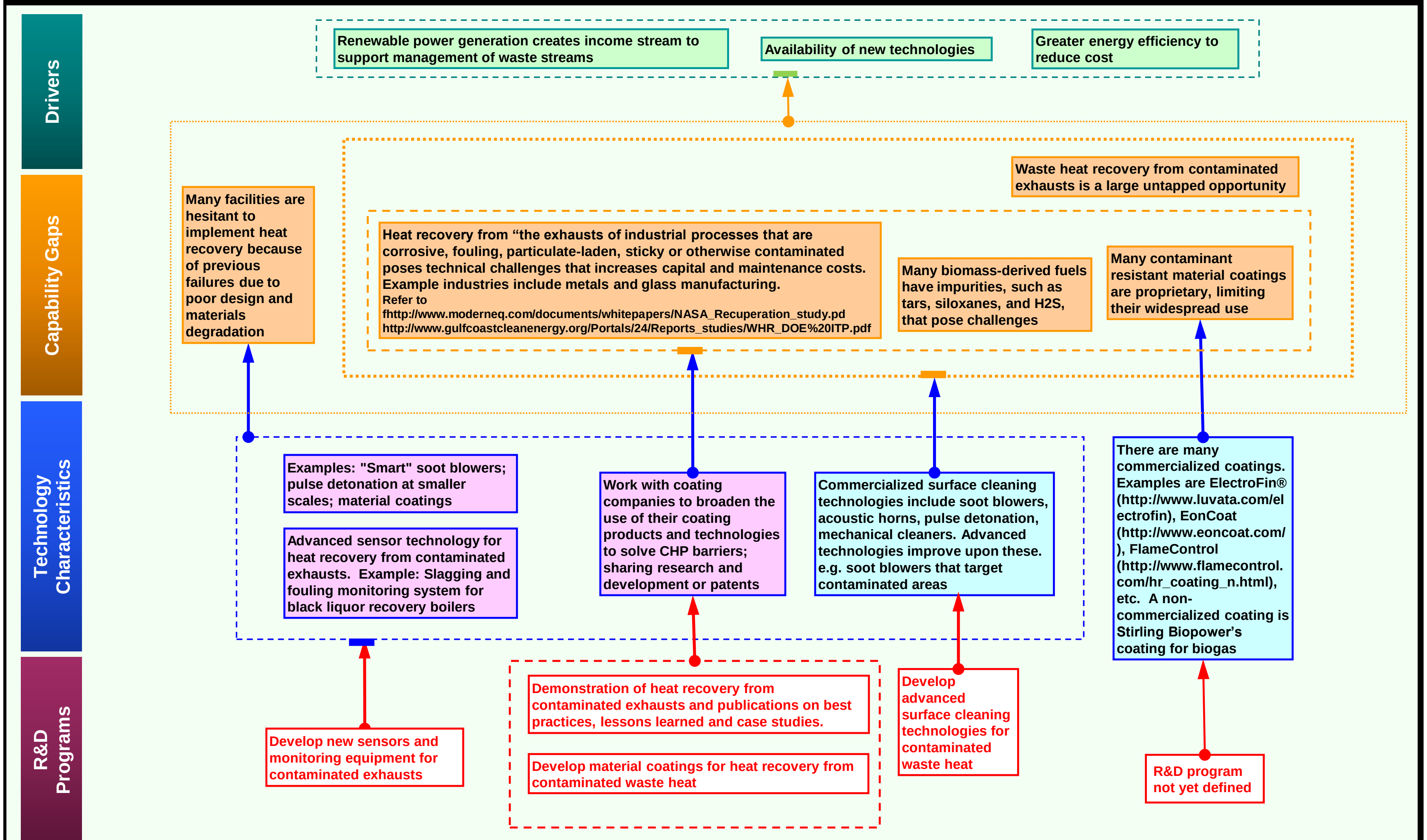
Combined Heat and Power (CHP)

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Production (3 of 7)

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Demonstration of heat recovery from contaminated exhausts and publications on best practices, lessons learned and case studies. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop advanced surface cleaning technologies for contaminated waste heat. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop new sensors and monitoring equipment for contaminated exhausts. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop material coatings for heat recovery from contaminated waste heat. Refer to Ichiro Suzuki, *Corrosion-Resistant Coatings Technology* (New York: Marcel Dekker [Taylor & Franicis Group], 1989)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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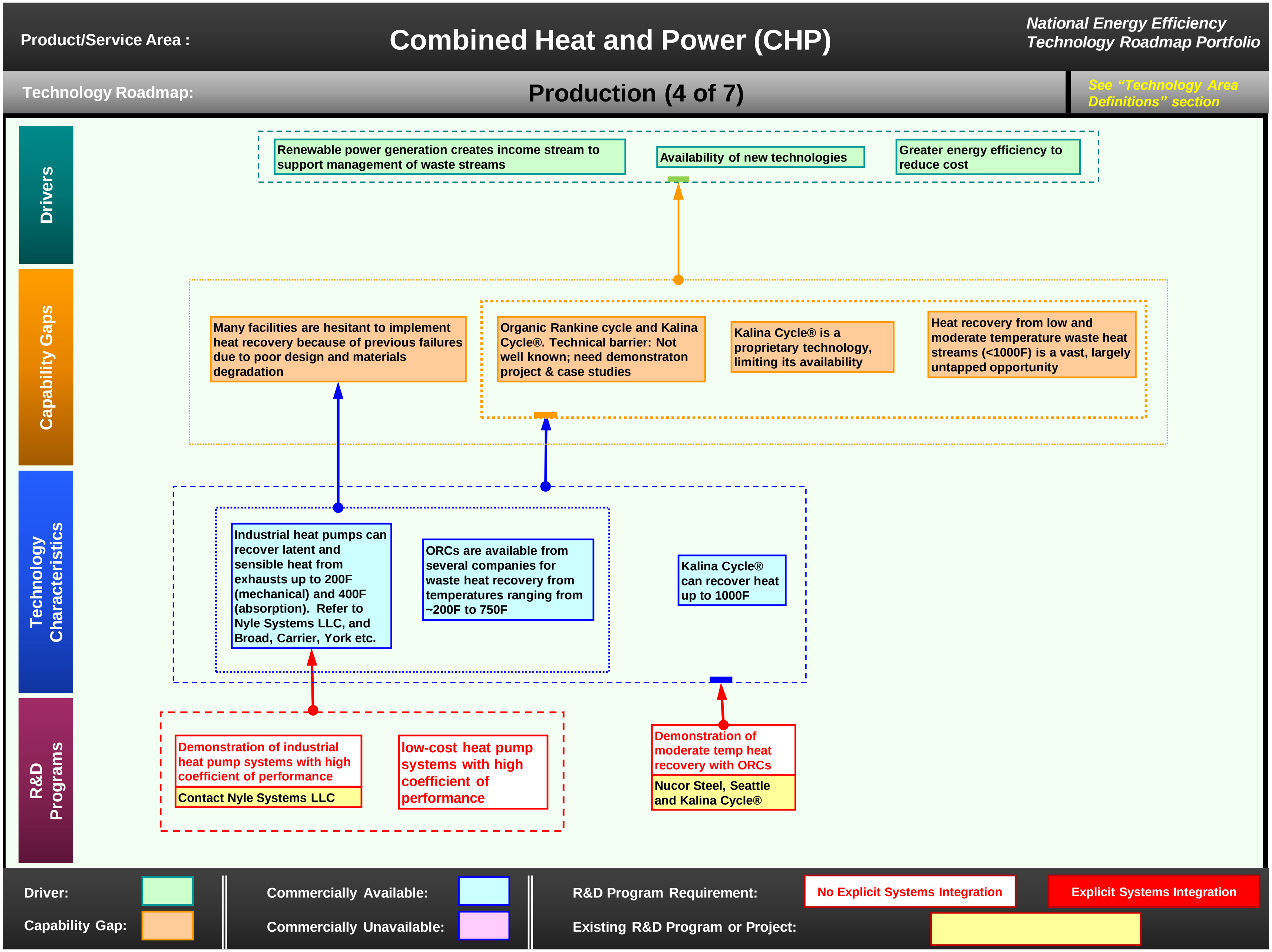
Product/Service Area :
Combined Heat and Power (CHP)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Production (4 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Renewable power generation creates income stream to support management of waste streams
Availability of new technologies
Greater energy efficiency to reduce cost
Many facilities are hesitant to implement heat recovery because of previous failures due to poor design and materials degradation
Organic Rankine cycle and Kalina Cycle®. Technical barrier: Not well known; need demonstraton project & case studies
Kalina Cycle® is a proprietary technology, limiting its availability
Heat recovery from low and moderate temperature waste heat streams (<1000F) is a vast, largely untapped opportunity
Industrial heat pumps can recover latent and sensible heat from exhausts up to 200F (mechanical) and 400F (absorption). Refer to Nyle Systems LLC, and Broad, Carrier, York etc.
ORCs are available from several companies for waste heat recovery from temperatures ranging from ~200F to 750F
Kalina Cycle® can recover heat up to 1000F
Demonstration of industrial heat pump systems with high coefficient of performance
Contact Nyle Systems LLC
low-cost heat pump systems with high coefficient of performance
Demonstration of moderate temp heat recovery with ORCs
Nucor Steel, Seattle and Kalina Cycle®
Driver:
Capability Gap:
Commercially Available:
Commercially Unavailable:
R&D Program Requirement:
No Explicit Systems Integration
Explicit Systems Integration
Existing R&D Program or Project:

R&D Program Summaries

Demonstration of industrial heat pump systems with high coefficient of performance. (Summary not yet provided.)

Existing research: For existing research, workshop participants suggested contact Nyle Systems LLC..

Key research questions:

1. Questions not yet specified

Demonstration of moderate temp heat recovery with Organic Rankine Cycles (ORCs). (Summary not yet provided.)

Existing research: For existing research, workshop participants suggested Nucor Steel, Seattle and Kalina Cycle®.

Key research questions:

1. Questions not yet specified

Low-cost heat pump systems with high coefficient of performance. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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Product/Service Area :

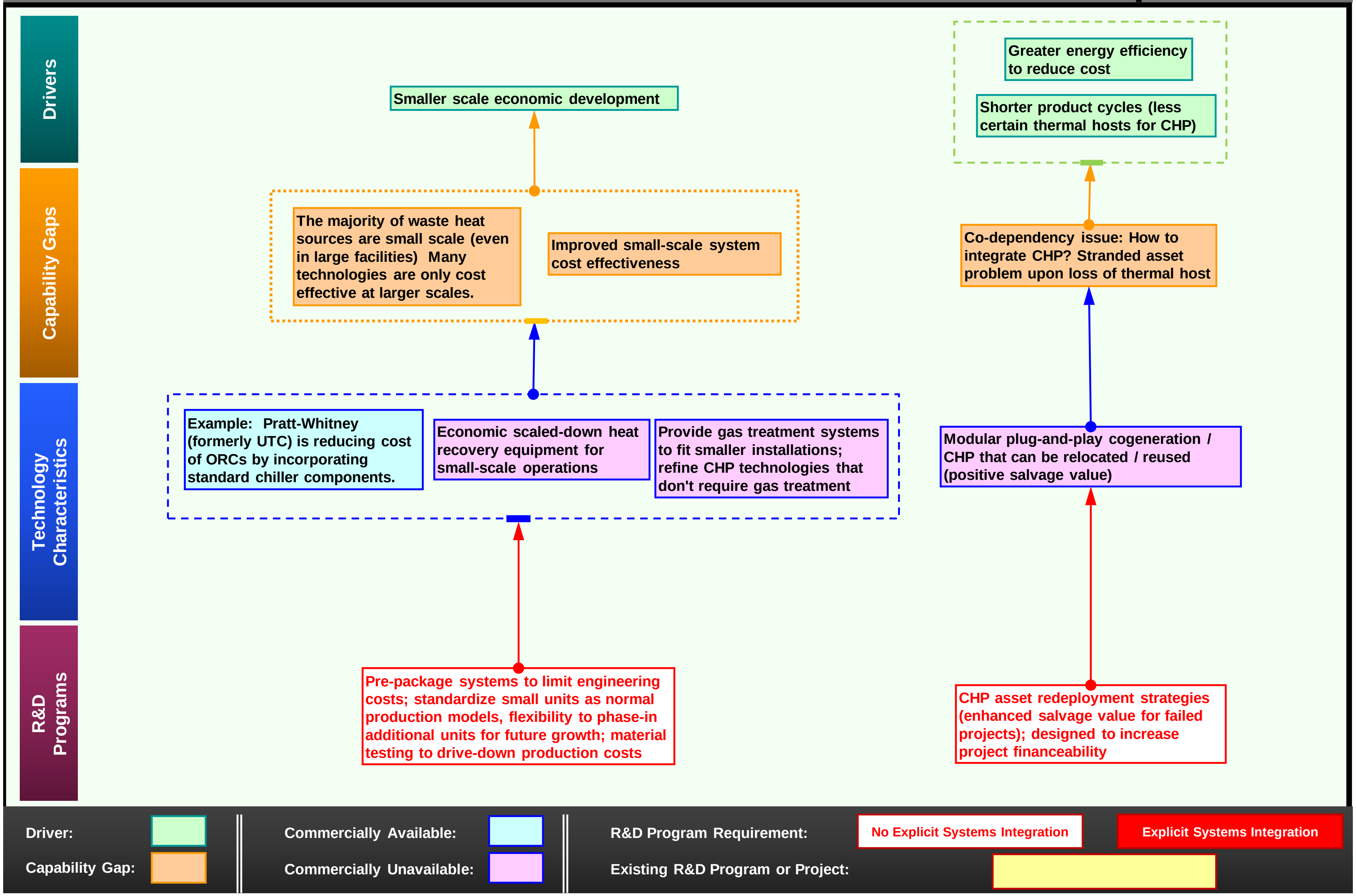
Combined Heat and Power (CHP)

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Production (5 of 7)

See "Technology Area Definitions" section



R&D Program Summaries

CHP asset redeployment strategies. Enhanced salvage value for failed projects designed to increase project financeability.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Pre-package systems. Limit engineering costs; standardize small units as normal production models, flexibility to phase-in additional units for future growth; material testing to drive-down production costs.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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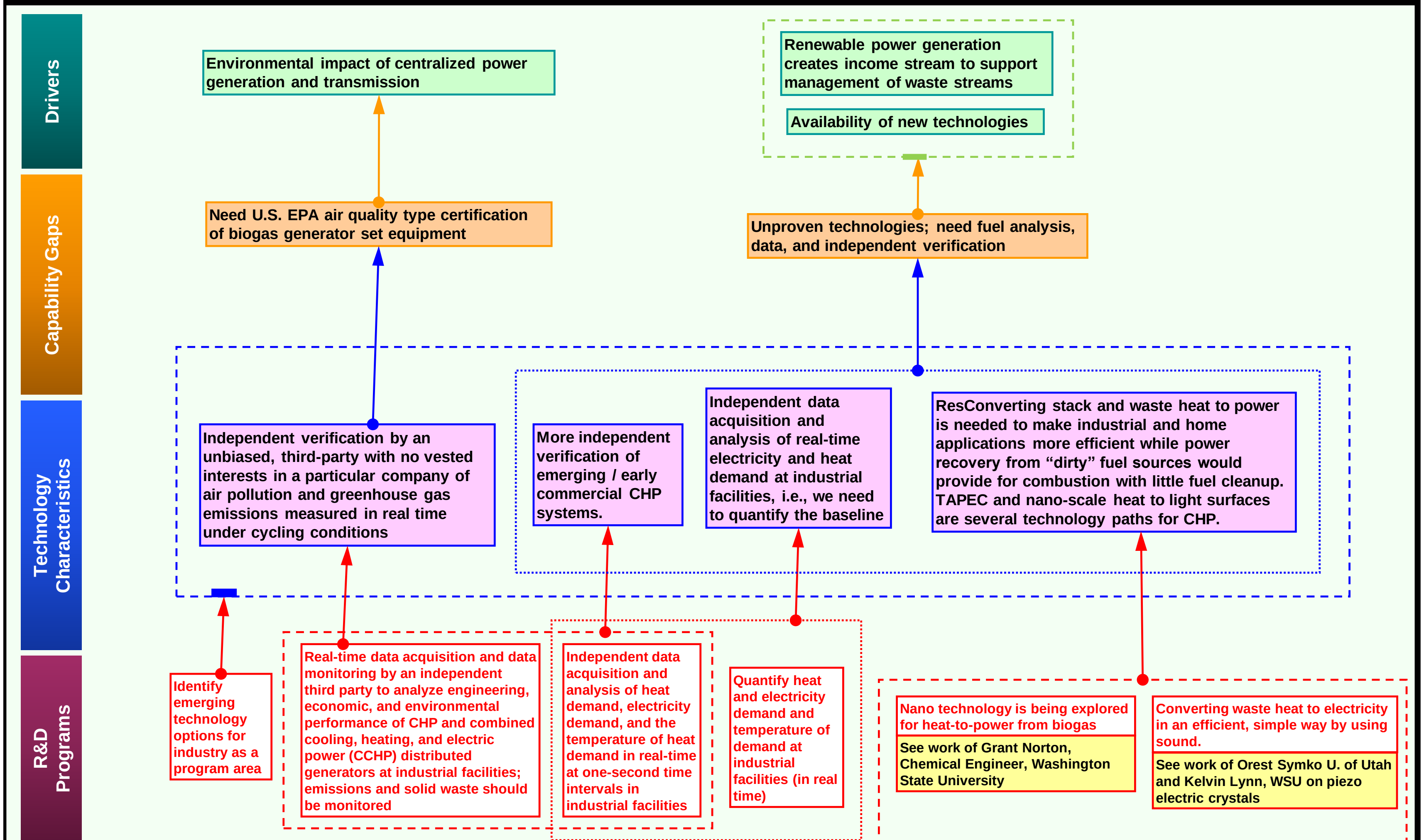
Product/Service Area :

Combined Heat and Power (CHP)

Technology Roadmap:

Production (6 of 7)

See "Technology Area Definitions" section



Driver: Capability Gap: Commercially Available: Commercially Unavailable: R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration. Existing R&D Program or Project:

R&D Program Summaries

Converting waste heat to electricity in an efficient, simple way by using sound.

Industrial settings such as stack heat using thermo acoustic piezo energy conversion (TAPEC) but also in home.

Existing research: See work of Orest Symko U. of Utah (http://www.physics.utah.edu/people/faculty/symko.html), and Kelvin Lynn, WSU on piezo electric crystals http://www.cmr.wsu.edu/center_director).

Key research questions:

1. Questions not yet specified

Nano technology is being explored for heat-to-power from biogas.

(Summary not yet provided.)

Existing research: See work of Grant Norton, Chemical Engineer, Washington State University (http://www.mme.wsu.edu/~norton/).

Key research questions:

1. Questions not yet specified

Identify emerging technology options for industry as a program area.

(Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Independent data acquisition and analysis of heat demand, electricity demand, and the temperature of heat demand in real-time at one-second time intervals in industrial facilities.

(Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Real-time data acquisition and data monitoring.

To be conducted by an independent third party to analyze engineering, economic, and environmental performance of CHP and combined cooling, heating, and electric power (CCHP) distributed generators at industrial facilities; emissions and solid waste should be monitored

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Quantify heat and electricity demand and temperature of demand at industrial facilities (in real time).

(Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

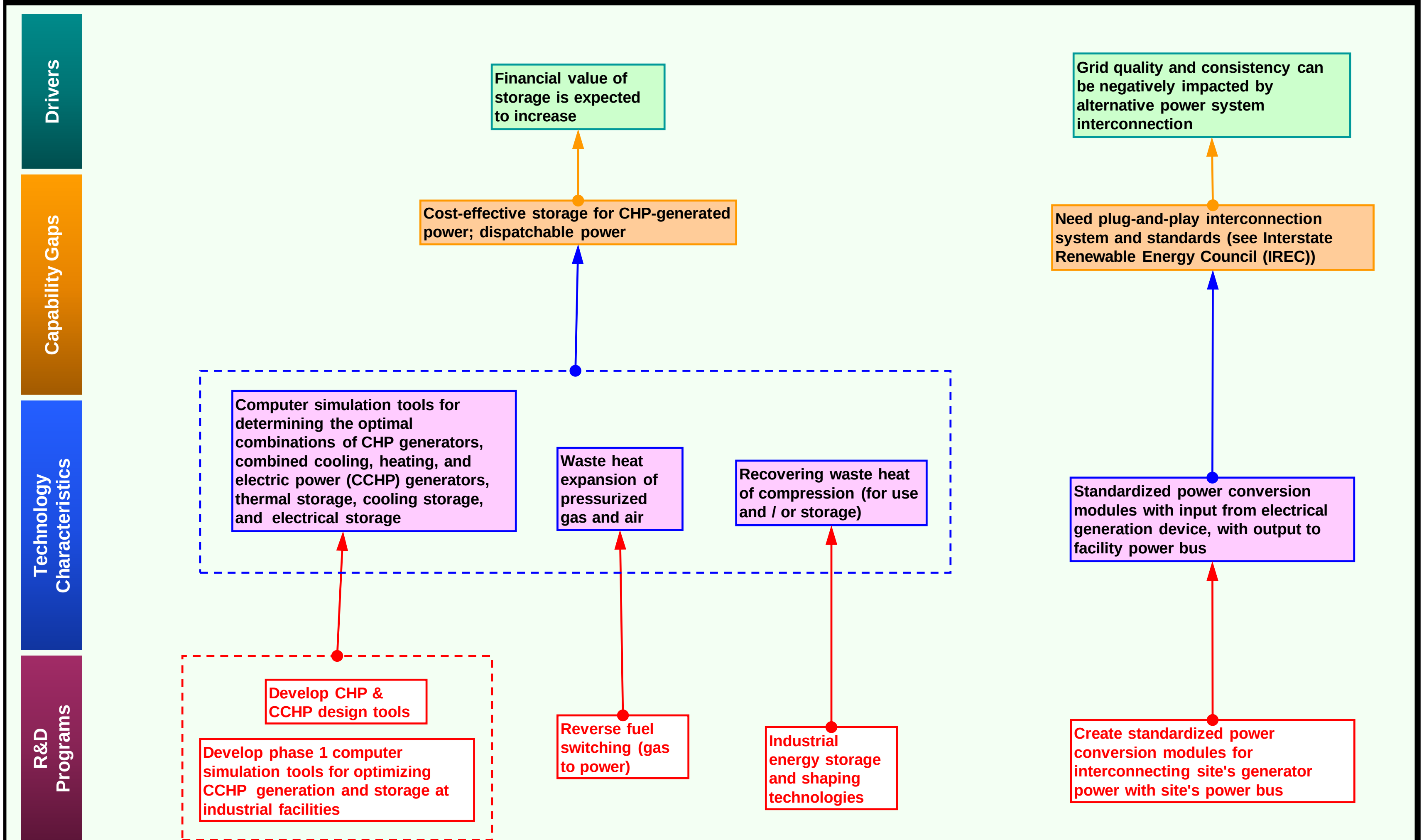
Back to Table of Contents

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Production (7 of 7)**

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Create standardized power conversion modules for interconnecting site's generator power with site's power bus. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop phase 1 computer simulation tools for optimizing CCHP generation and storage at industrial facilities. Computer simulation tools can identify optimal installed capacities, control strategies, and deployment and installation approaches for combined cooling, heating, and electric power (CCHP) systems; phase III models could be ultimately used by industry directly.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop CHP and CCHP design tools. Tools to be used by industry to select the optimal installed capacity of a CHP or combined cooling, heating, and electric power (CCHP) generator for a facility as well as optimal operating and control strategies

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Industrial energy storage and shaping technologies. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Reverse fuel switching (gas to power). (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Back to Table of Contents

Product/Service Area :

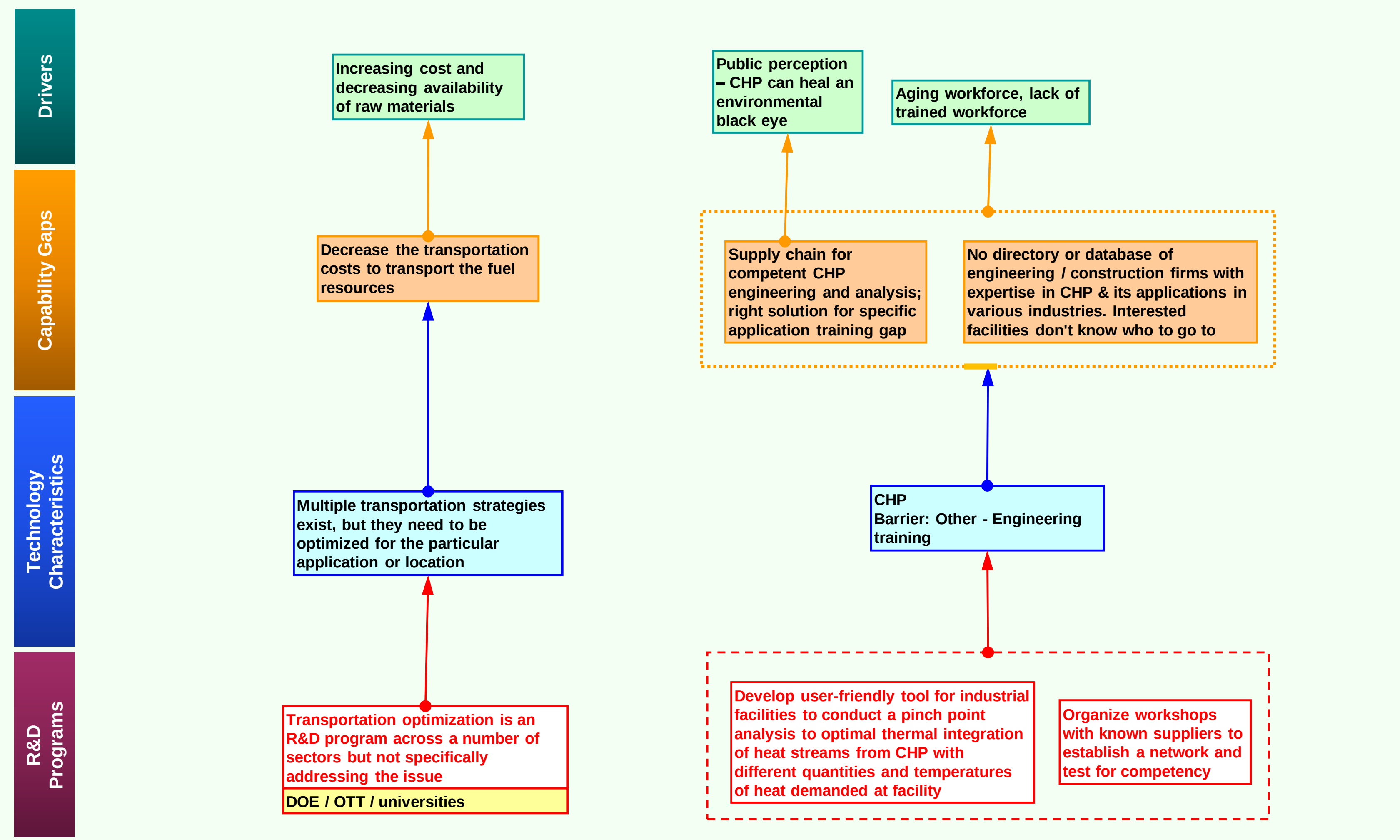
Combined Heat and Power (CHP)

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Resources (1 of 7)

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Transportation optimization. This R&D program applies across a number of sectors but these have not specifically addressed issues and concerns specific to industrial CHP systems.

Existing research: Stakeholders indicated ongoing research at the U.S. Department of Energy (DOE) and the DOE's Office of Transportation Technologies (OTT) within the Energy Efficiency and Renewable Energy (EERE), as well as at universities.

- DOE's Office of Transportation Technologies (OTT): http://www1.eere.energy.gov/vehiclesandfuels/

Key research questions:

1. Questions not yet specified

Develop user-friendly tool for industrial facilities to conduct a pinch point analysis to optimal thermal integration of heat streams from CHP with different quantities and temperatures of heat demanded at facility. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Organize workshops with known suppliers to establish a network and test for competency. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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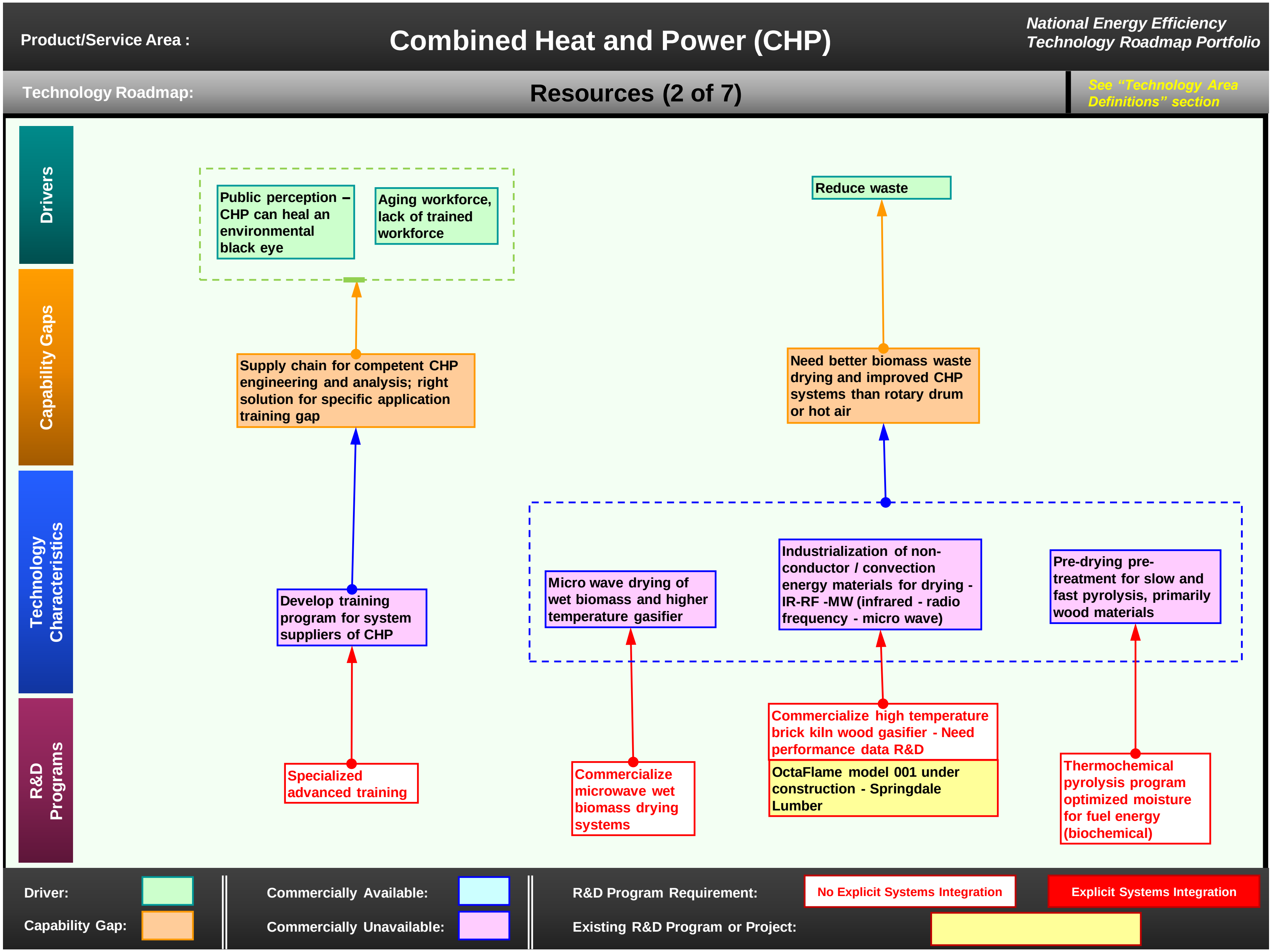

Product/Service Area :
Combined Heat and Power (CHP)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Resources (2 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Public perception – CHP can heal an environmental black eye
Aging workforce, lack of trained workforce
Reduce waste
Supply chain for competent CHP engineering and analysis; right solution for specific application training gap
Need better biomass waste drying and improved CHP systems than rotary drum or hot air
Develop training program for system suppliers of CHP
Micro wave drying of wet biomass and higher temperature gasifier
Industrialization of non-conductor / convection energy materials for drying - IR-RF -MW (infrared - radio frequency - micro wave)
Pre-drying pre-treatment for slow and fast pyrolysis, primarily wood materials
Specialized advanced training
Commercialize microwave wet biomass drying systems
Commercialize high temperature brick kiln wood gasifier - Need performance data R&D
OctaFlame model 001 under construction - Springdale Lumber
Thermochemical pyrolysis program optimized moisture for fuel energy (biochemical)
Driver:
Capability Gap:
Commercially Available:
Commercially Unavailable:
R&D Program Requirement:
No Explicit Systems Integration
Explicit Systems Integration
Existing R&D Program or Project:

R&D Program Summaries

Commercialize high temperature brick kiln wood gasifier. Need performance data R&D on brick kiln wood gasifier system now being evaluated at Springdale Lumber in Spokane, Washington.

Existing research: Borgford BioEnergy LLC's OctaFlame model 001 is under construction at Springdale Lumber; see http://www.borgfordbioenergy.net/index.htm.

Key research questions:

1. Questions not yet specified

Specialized advanced training. Support and expand current programs to train graduates and post doctors for renewable industry with emphasis on new technology and ability to communicate complex ideas with the public.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Commercialize microwave wet biomass drying systems. For more information contact Rotawave Ltd. out of the U.K., rotawave.com.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Thermochemical pyrolysis program optimized moisture for fuel energy (biochemical). For more information contact Manuel Garcia Perez at Washington State University, www.bsyse.wsu.edu/garcia-perez.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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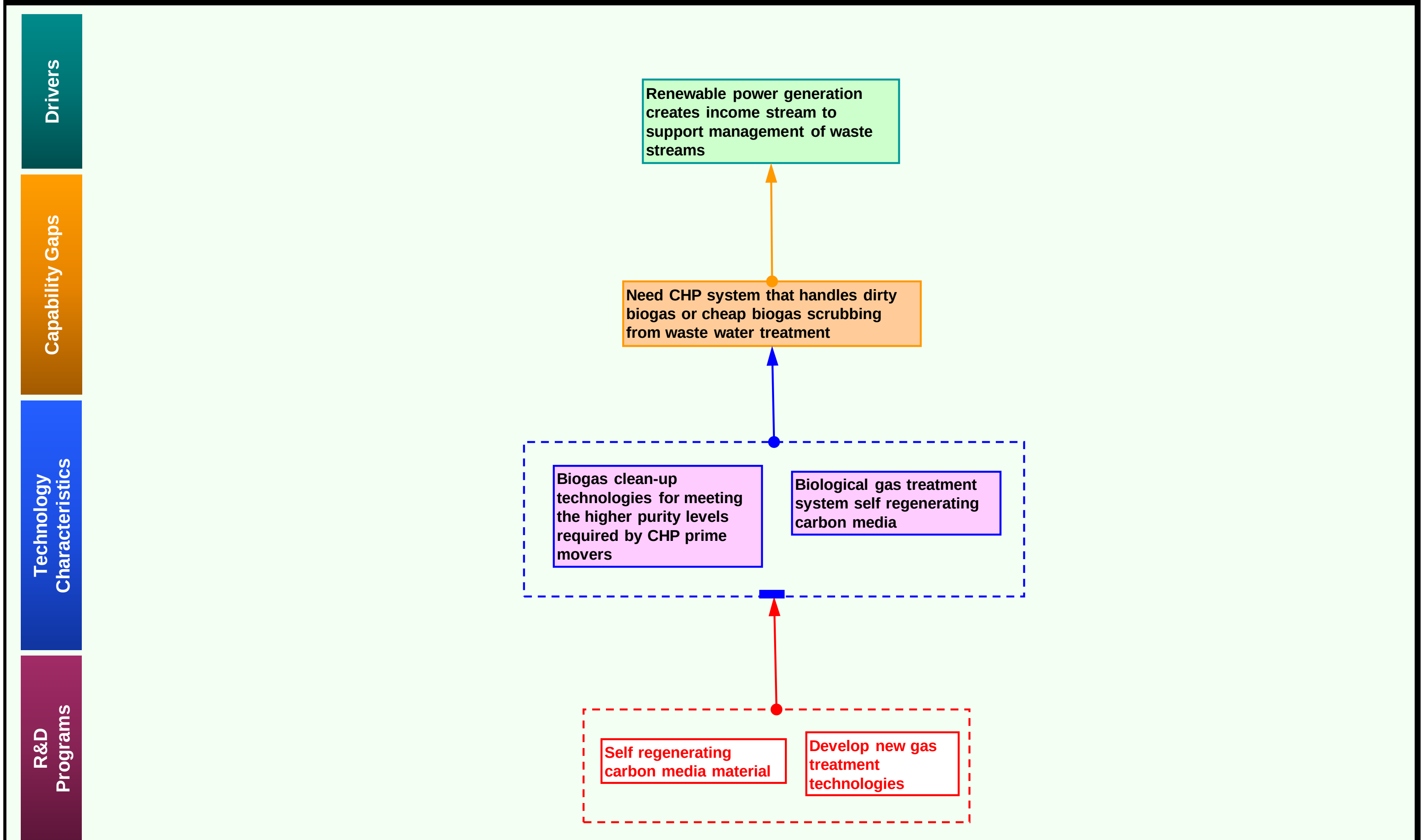
Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Resources (3 of 7)**

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Self regenerating carbon media material. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop new gas treatment technologies. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

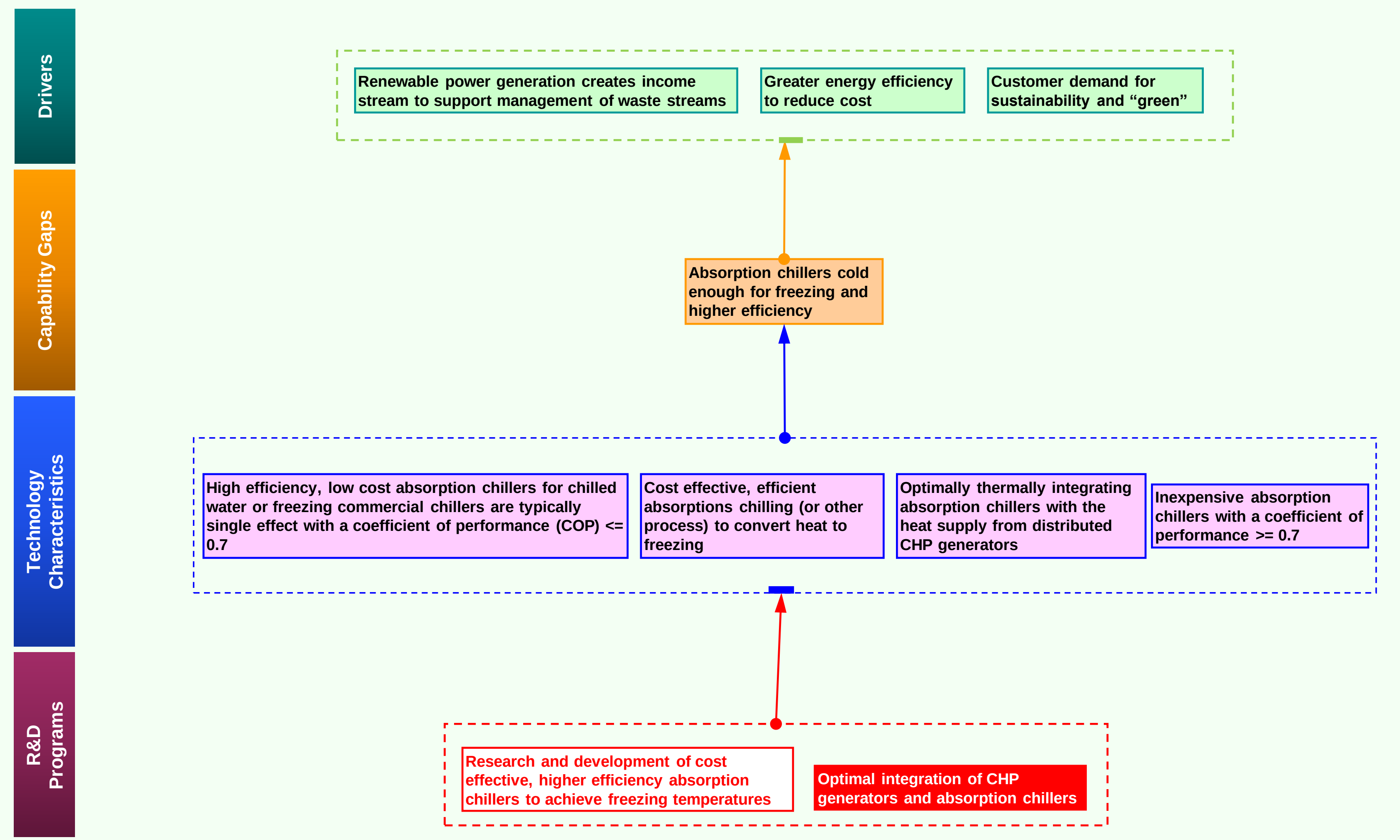
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Resources (4 of 7)**

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Cost effective, higher efficiency absorption chillers to achieve freezing temperatures. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Optimal integration of CHP generators and absorption chillers. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Product/Service Area :

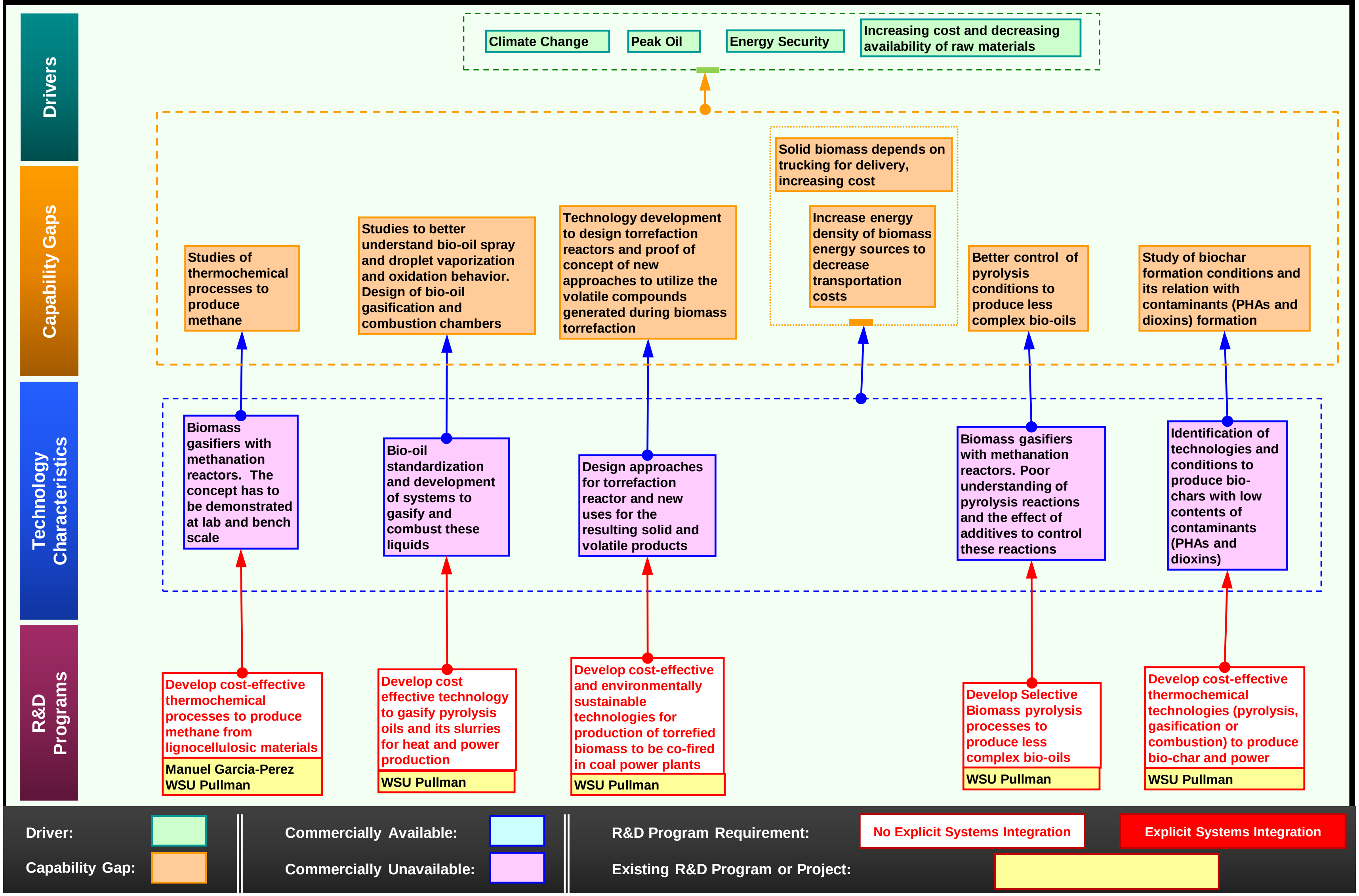
Combined Heat and Power (CHP)

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Resources (5 of 7)

See "Technology Area Definitions" section



R&D Program Summaries

Cost-effective and environmentally sustainable technologies for production of torrefied biomass to be co-fired in coal power plants.

(Summary not yet provided.)

Existing research: Researchers at Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources (CSANR)are conducting R&D about producing torrefied biomass; see http://csanr.wsu.edu/.

Key research questions:

1. Questions not yet specified

Cost-effective technology to gasify pyrolysis oils and its slurries for heat and power production.

(Summary not yet provided.)

Existing research: Researchers at Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources (CSANR)are conducting R&D about gasifying pyrolysis oils and its slurries; see http://csanr.wsu.edu/.

Key research questions:

1. Questions not yet specified

Cost-effective thermochemical processes to produce methane from lignocellulosic materials.

(Summary not yet provided.)

Existing research: Contact Manuel Garcia Perez at Washington State University, www.bsyse.wsu.edu/garcia-perez.

Key research questions:

1. Questions not yet specified

Cost-effective thermochemical technologies (pyrolysis, gasification or combustion) to produce bio-char and power.

(Summary not yet provided.)

Existing research: Researchers at Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources (CSANR)are conducting R&D about producing bio-char and power using Cost-effective thermochemical technologies; see http://csanr.wsu.edu/.

Key research questions:

1. Questions not yet specified

Selective biomass pyrolysis processes to produce less complex bio-oils.

(Summary not yet provided.)

Existing research: Researchers at Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources (CSANR)are conducting R&D about producing less complex bio-oils from the pyrolysis processes; see http://csanr.wsu.edu/.

Key research questions:

1. Questions not yet specified

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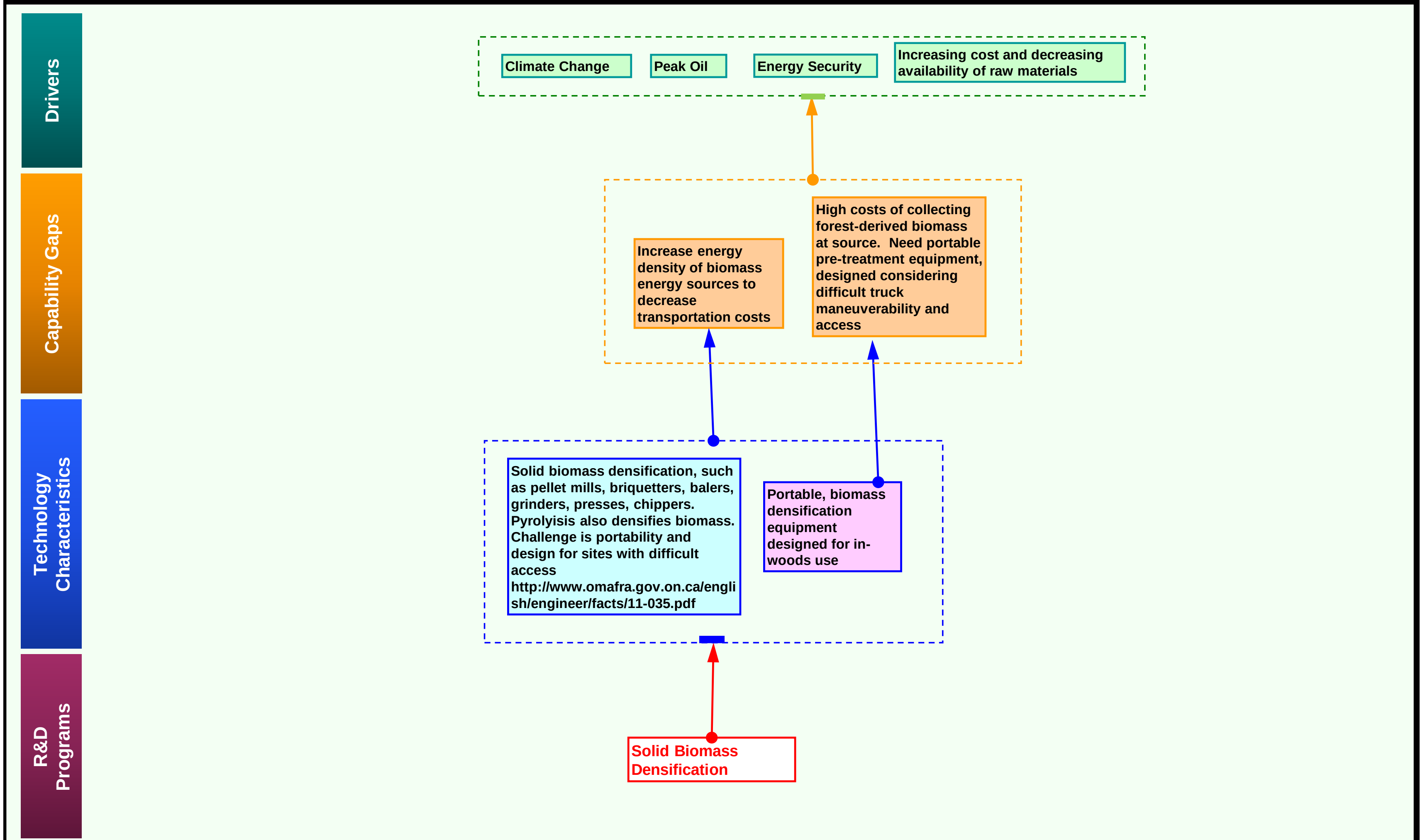
Technology Roadmap: **Resources (6 of 7)**

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Solid biomass densification. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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Product/Service Area :

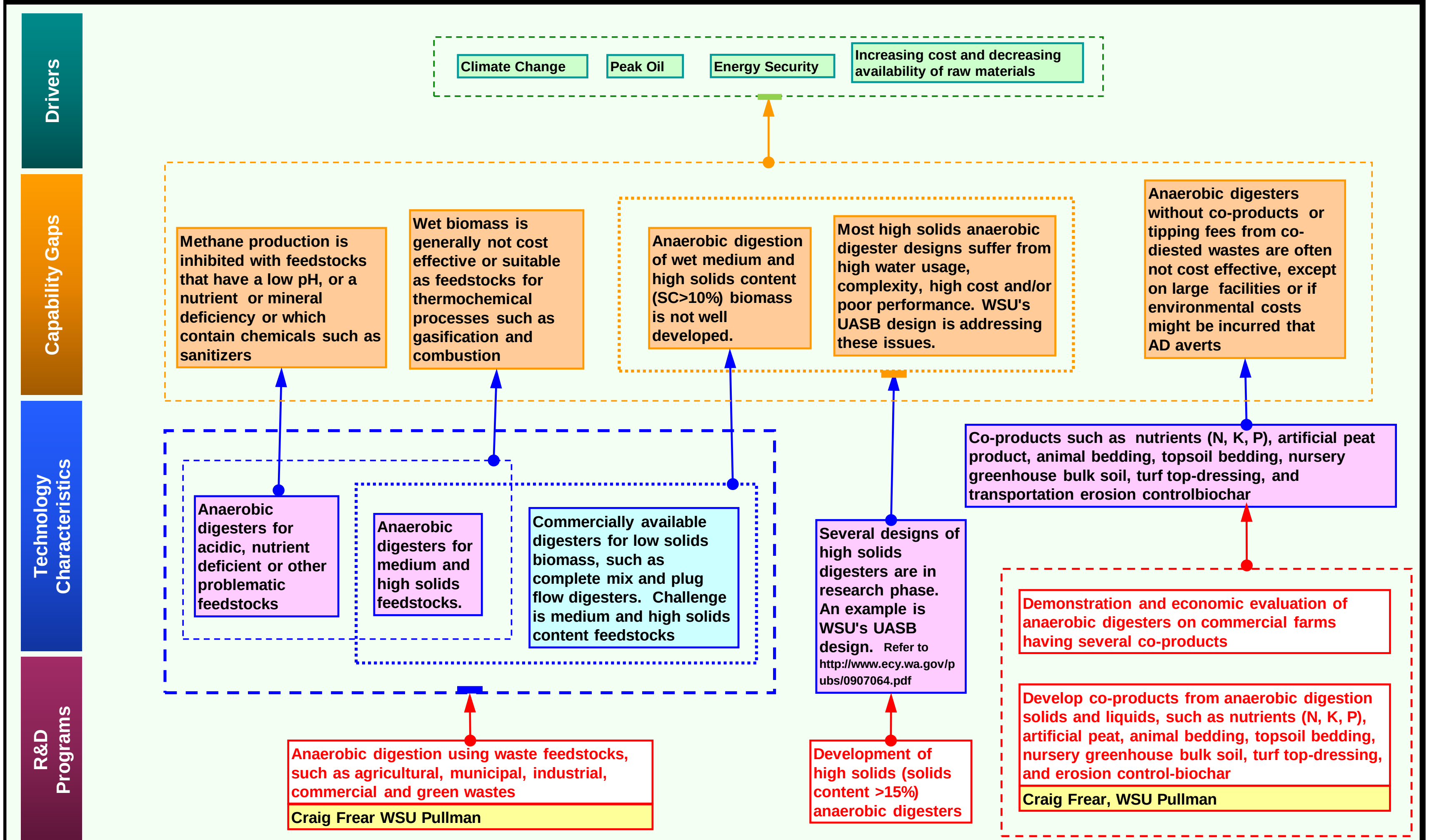
Combined Heat and Power (CHP)

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Resources (7 of 7)

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Anaerobic digestion using waste feedstocks. Digestion to include agricultural, municipal, inudstrial, commercial and green wastes.

Existing research: Contact Craig Frear, Washington State University, http://www.bsyse.wsu.edu/core/directory/faculty/cfrear.html.

Key research questions:

1. Questions not yet specified

Develop co-products from anaerobic digestion solids and liquids. Co-products to include nutrients (N, K, P), artificial peat, animal bedding, topsoil bedding, nursery greenhouse bulk soil, turf top-dressing, and erosion control-biochar.

Existing research: Contact Craig Frear, Washington State University, http://www.bsyse.wsu.edu/core/directory/faculty/cfrear.html.

Key research questions:

1. Questions not yet specified

Demonstration and economic evaluation of anaerobic digesters on commercial farms having several co-products. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop high solids (solids content >15%) anaerobic digesters. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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Product/Service Area :

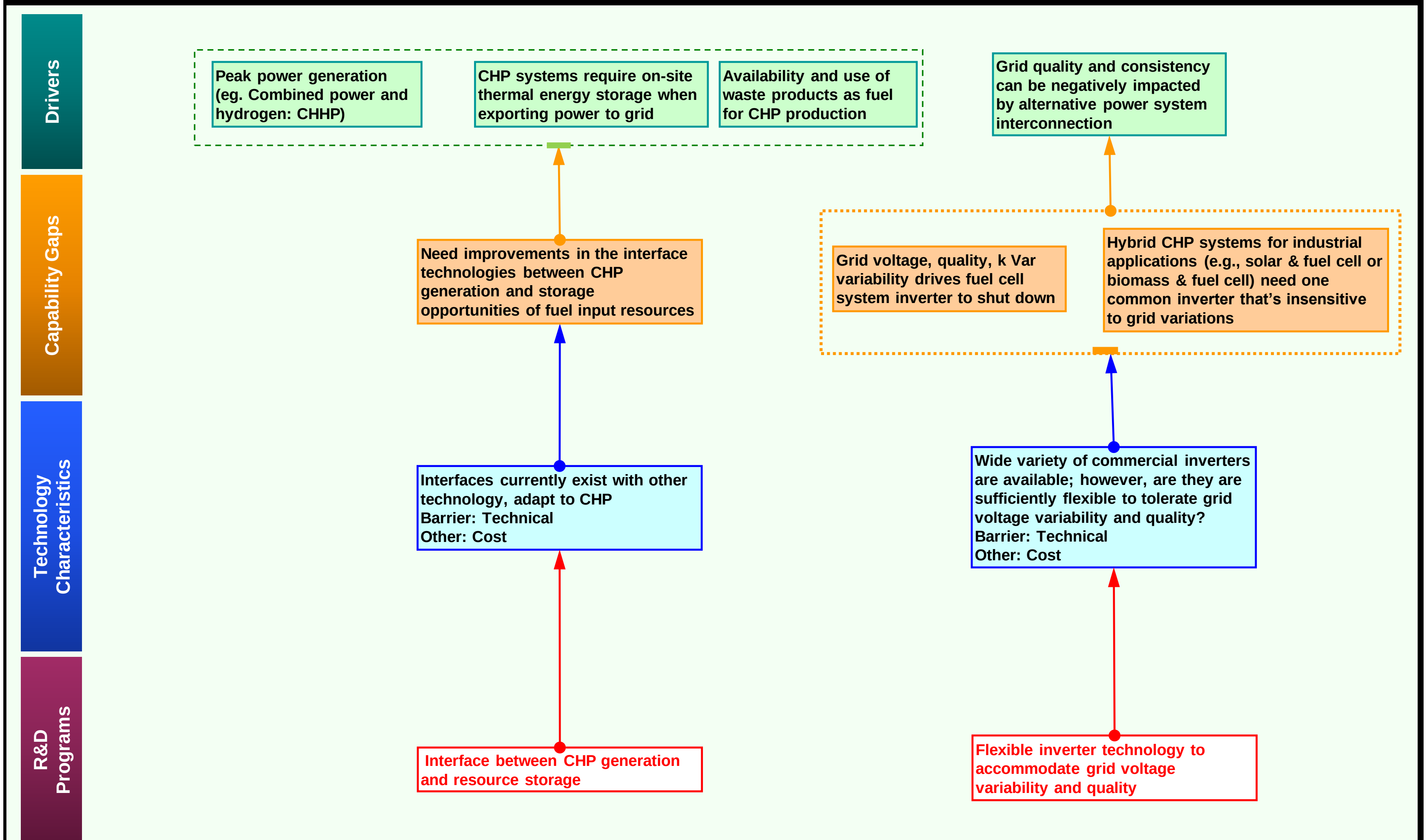
Combined Heat and Power (CHP)

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Delivery (1 of 8)

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Interface between CHP generation and resource storage. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

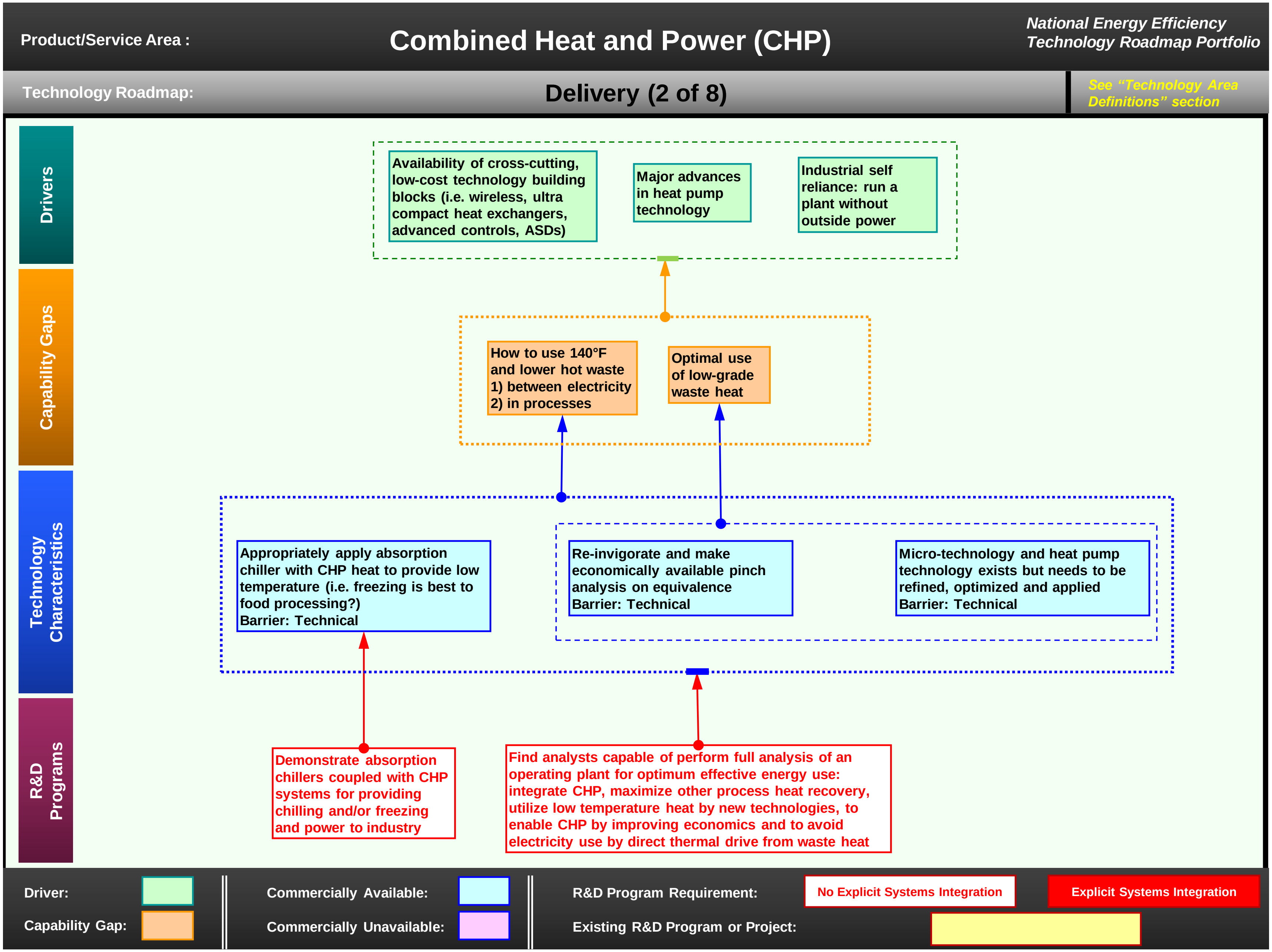
1. Questions not yet specified

Flexible inverter technology to accommodate grid voltage variability and quality. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified


Product/Service Area :
Combined Heat and Power (CHP)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Delivery (2 of 8)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Availability of cross-cutting, low-cost technology building blocks (i.e. wireless, ultra compact heat exchangers, advanced controls, ASDs)
Major advances in heat pump technology
Industrial self reliance: run a plant without outside power
How to use 140°F and lower hot waste 1) between electricity 2) in processes
Optimal use of low-grade waste heat
Appropriately apply absorption chiller with CHP heat to provide low temperature (i.e. freezing is best to food processing?) Barrier: Technical
Re-invigorate and make economically available pinch analysis on equivalence Barrier: Technical
Micro-technology and heat pump technology exists but needs to be refined, optimized and applied Barrier: Technical
Demonstrate absorption chillers coupled with CHP systems for providing chilling and/or freezing and power to industry
Find analysts capable of perform full analysis of an operating plant for optimum effective energy use: integrate CHP, maximize other process heat recovery, utilize low temperature heat by new technologies, to enable CHP by improving economics and to avoid electricity use by direct thermal drive from waste heat
Driver:
Capability Gap:
Commercially Available:
Commercially Unavailable:
R&D Program Requirement:
No Explicit Systems Integration
Explicit Systems Integration
Existing R&D Program or Project:

R&D Program Summaries

Demonstrate absorption chillers coupled with CHP systems for providing chilling and/or freezing and power to industry. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Analysts capable of perform full analysis of an operating plant for optimum effective energy use. There is a need for qualified analysts to integrate CHP, maximize other process heat recovery, utilize low temperature heat by new technologies, to enable CHP by improving economics and to avoid electricity use by direct thermal drive from waste heat.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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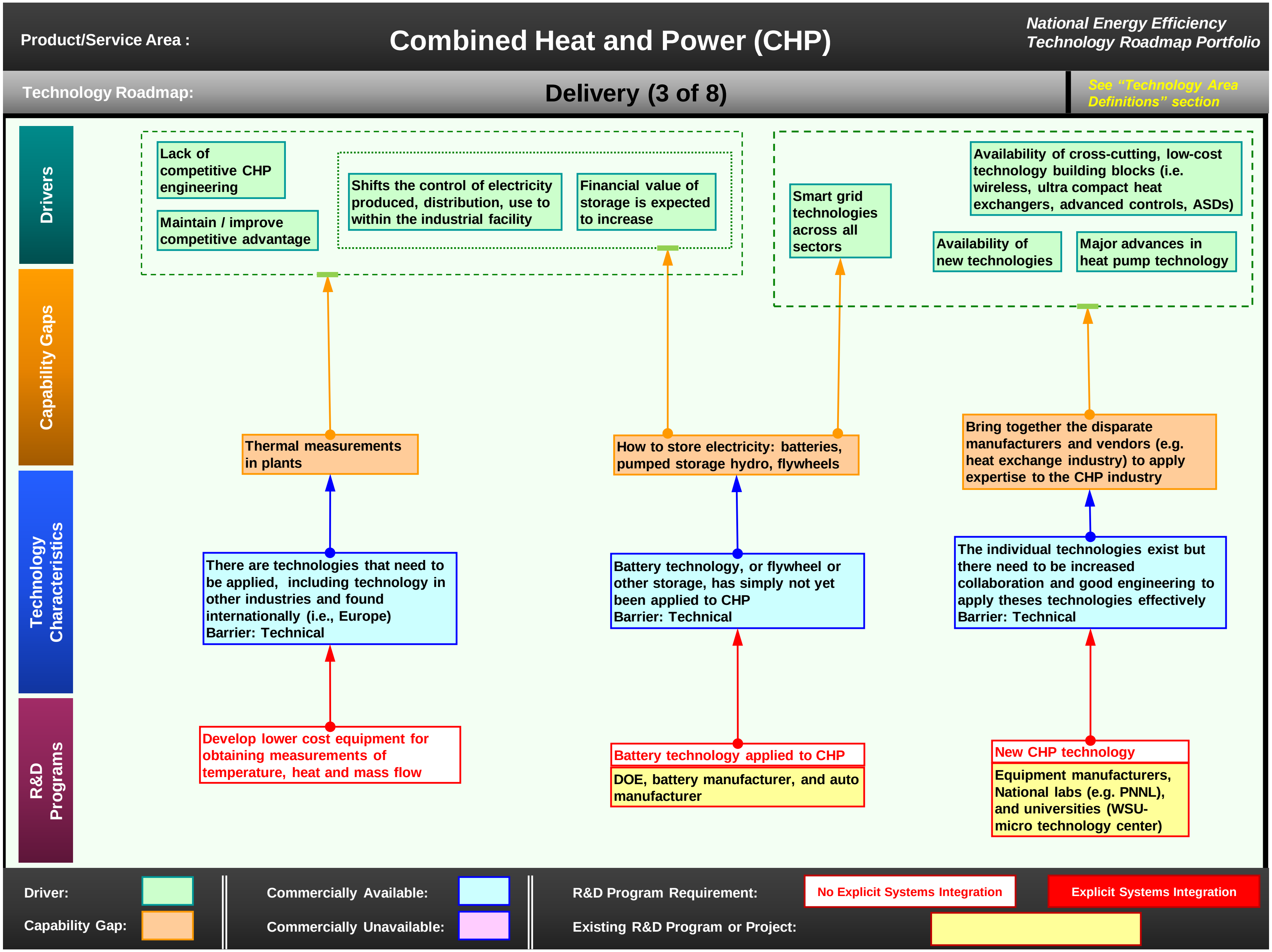
Product/Service Area :
Combined Heat and Power (CHP)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Delivery (3 of 8)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Lack of competitive CHP engineering
Maintain / improve competitive advantage
Shifts the control of electricity produced, distribution, use to within the industrial facility
Financial value of storage is expected to increase
Smart grid technologies across all sectors
Availability of cross-cutting, low-cost technology building blocks (i.e. wireless, ultra compact heat exchangers, advanced controls, ASDs)
Availability of new technologies
Major advances in heat pump technology
Thermal measurements in plants
How to store electricity: batteries, pumped storage hydro, flywheels
Bring together the disparate manufacturers and vendors (e.g. heat exchange industry) to apply expertise to the CHP industry
There are technologies that need to be applied, including technology in other industries and found internationally (i.e., Europe)
Barrier: Technical
Battery technology, or flywheel or other storage, has simply not yet been applied to CHP
Barrier: Technical
The individual technologies exist but there need to be increased collaboration and good engineering to apply theses technologies effectively
Barrier: Technical
Develop lower cost equipment for obtaining measurements of temperature, heat and mass flow
Battery technology applied to CHP
DOE, battery manufacturer, and auto manufacturer
New CHP technology
Equipment manufacturers, National labs (e.g. PNNL), and universities (WSU-micro technology center)
Driver:
Capability Gap:
Commercially Available:
Commercially Unavailable:
R&D Program Requirement:
No Explicit Systems Integration
Explicit Systems Integration
Existing R&D Program or Project:

R&D Program Summaries

Battery technology applied to CHP. There is much ongoing battery technology R&D but it is has not been directed at CHP applications (at least wide-spread).

Existing research: Research ongoing at the U.S. DOE, battery manufacturers, and auto manufacturers.

Key research questions:

1. Questions not yet specified

New CHP technologies. U.S. DOE and every major technology manufacturer is working on new technologies to fill this gap; the challenge is to bring these technologies to the CHP industry.

Existing research: Research ongoing at equipment manufacturers, National labs (e.g. PNNL), and universities (WSU-micro technology center).

Key research questions:

1. Questions not yet specified

Develop lower-cost equipment for obtaining measurements of temperature, heat, and mass flow. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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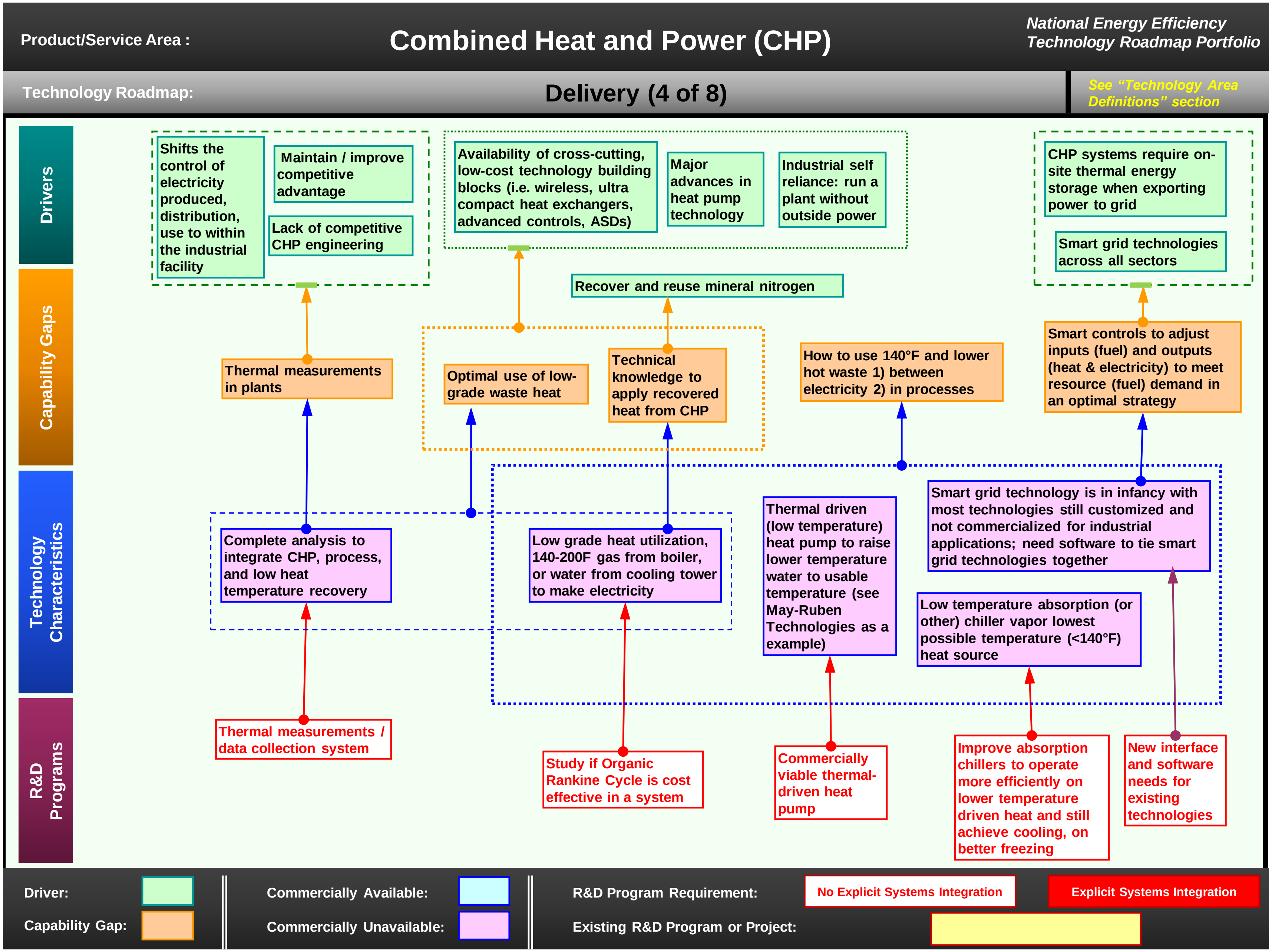
Product/Service Area :
Combined Heat and Power (CHP)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Delivery (4 of 8)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Shifts the control of electricity produced, distribution, use to within the industrial facility
Maintain / improve competitive advantage
Lack of competitive CHP engineering
Availability of cross-cutting, low-cost technology building blocks (i.e. wireless, ultra compact heat exchangers, advanced controls, ASDs)
Major advances in heat pump technology
Industrial self reliance: run a plant without outside power
CHP systems require on-site thermal energy storage when exporting power to grid
Smart grid technologies across all sectors
Recover and reuse mineral nitrogen
Thermal measurements in plants
Optimal use of low-grade waste heat
Technical knowledge to apply recovered heat from CHP
How to use 140°F and lower hot waste 1) between electricity 2) in processes
Smart controls to adjust inputs (fuel) and outputs (heat & electricity) to meet resource (fuel) demand in an optimal strategy
Complete analysis to integrate CHP, process, and low heat temperature recovery
Low grade heat utilization, 140-200F gas from boiler, or water from cooling tower to make electricity
Thermal driven (low temperature) heat pump to raise lower temperature water to usable temperature (see May-Ruben Technologies as a example)
Smart grid technology is in infancy with most technologies still customized and not commercialized for industrial applications; need software to tie smart grid technologies together
Low temperature absorption (or other) chiller vapor lowest possible temperature (<140°F) heat source
Thermal measurements / data collection system
Study if Organic Rankine Cycle is cost effective in a system
Commercially viable thermal-driven heat pump
Improve absorption chillers to operate more efficiently on lower temperature driven heat and still achieve cooling, on better freezing
New interface and software needs for existing technologies
Driver:
Capability Gap:
Commercially Available:
Commercially Unavailable:
R&D Program Requirement:
No Explicit Systems Integration
Explicit Systems Integration
Existing R&D Program or Project:

R&D Program Summaries

Thermal measurements / data collection system. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Commercially viable thermal-driven heat pump. Need to lift low temperature (100°-140°F) heat to higher temperature (160°-200°F) so it can be utilized in process (reference: May-Ruben Technologies).

Existing research: None identified.

Key research questions:

1. Questions not yet specified

New interface and software for existing smart technologies. This could include smart technology for individual industrial equipment inside the plant linked to CHP system to give comprehensive ability to manage load and supply to meet price signals.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Improve absorption chillers to operate more efficiently on lower temperature driven heat and still achieve cooling, on better freezing. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Study if Organic Rankine Cycle is cost effective in a system. Input = 140°F H2O or 170°F boiler exhaust gas, output = 50°F H2O or cool exhaust gas, and heat pump process producing electricity.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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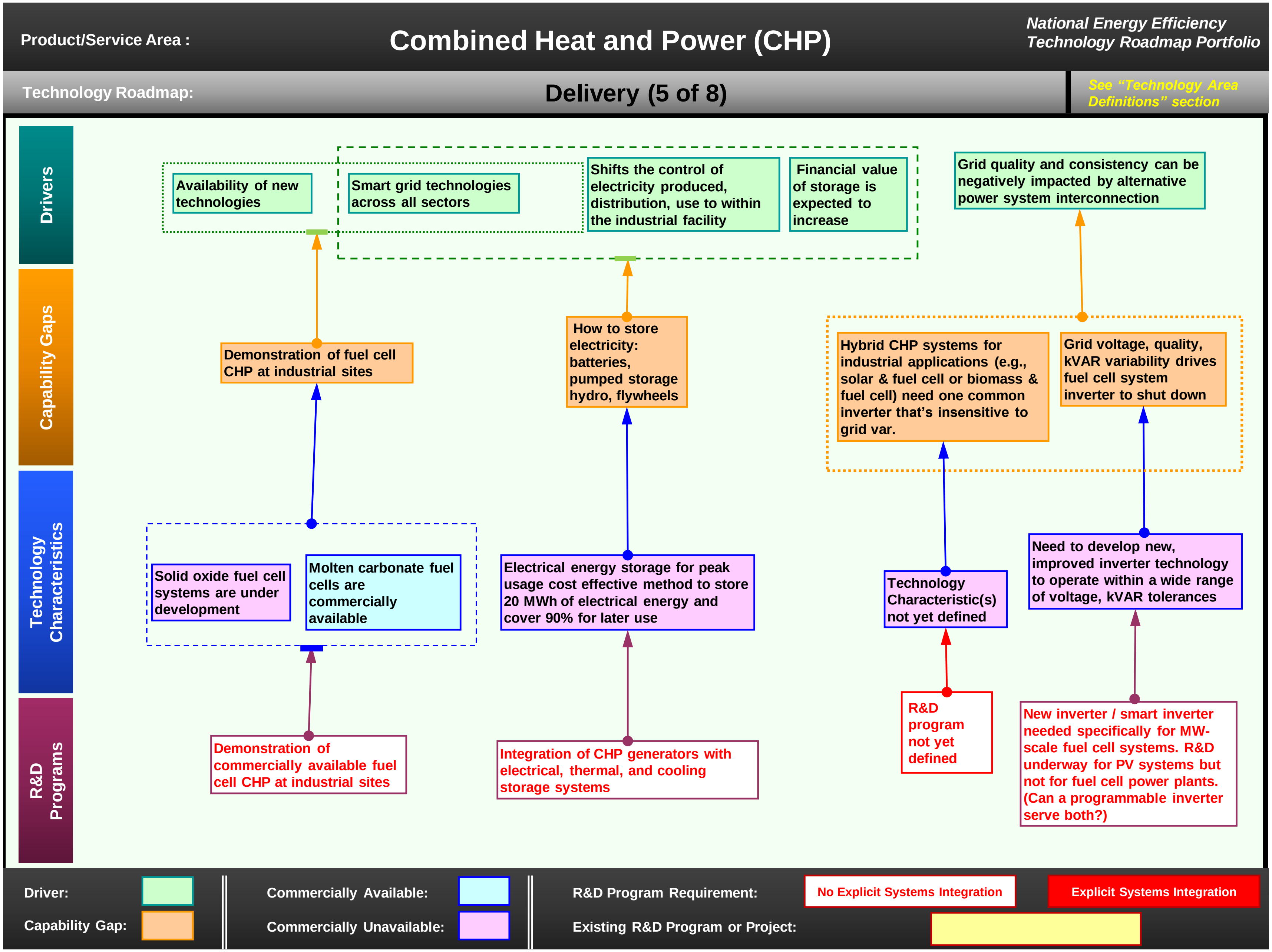
Product/Service Area :
Combined Heat and Power (CHP)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Delivery (5 of 8)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Availability of new technologies
Smart grid technologies across all sectors
Shifts the control of electricity produced, distribution, use to within the industrial facility
Financial value of storage is expected to increase
Grid quality and consistency can be negatively impacted by alternative power system interconnection
Demonstration of fuel cell CHP at industrial sites
How to store electricity: batteries, pumped storage hydro, flywheels
Hybrid CHP systems for industrial applications (e.g., solar & fuel cell or biomass & fuel cell) need one common inverter that's insensitive to grid var.
Grid voltage, quality, kVAR variability drives fuel cell system inverter to shut down
Solid oxide fuel cell systems are under development
Molten carbonate fuel cells are commercially available
Electrical energy storage for peak usage cost effective method to store 20 MWh of electrical energy and cover 90% for later use
Technology Characteristic(s) not yet defined
Need to develop new, improved inverter technology to operate within a wide range of voltage, kVAR tolerances
Demonstration of commercially available fuel cell CHP at industrial sites
Integration of CHP generators with electrical, thermal, and cooling storage systems
R&D program not yet defined
New inverter / smart inverter needed specifically for MW-scale fuel cell systems. R&D underway for PV systems but not for fuel cell power plants. (Can a programmable inverter serve both?)
Driver:
Capability Gap:
Commercially Available:
Commercially Unavailable:
R&D Program Requirement:
No Explicit Systems Integration
Explicit Systems Integration
Existing R&D Program or Project:

R&D Program Summaries

Demonstrate commercially-available fuel cell CHP at industrial sites. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Integrate CHP generators with electrical, thermal, and cooling storage systems. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

New inverter / smart inverter needed specifically for MW-scale fuel cell systems. R&D underway for photovoltaic (PV) systems but not for fuel cell power plants.

Existing research: None identified.

Key research questions:

1. Can a programmable inverter serve both photovoltaic and MW-scale fuel cell systems?

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Product/Service Area :

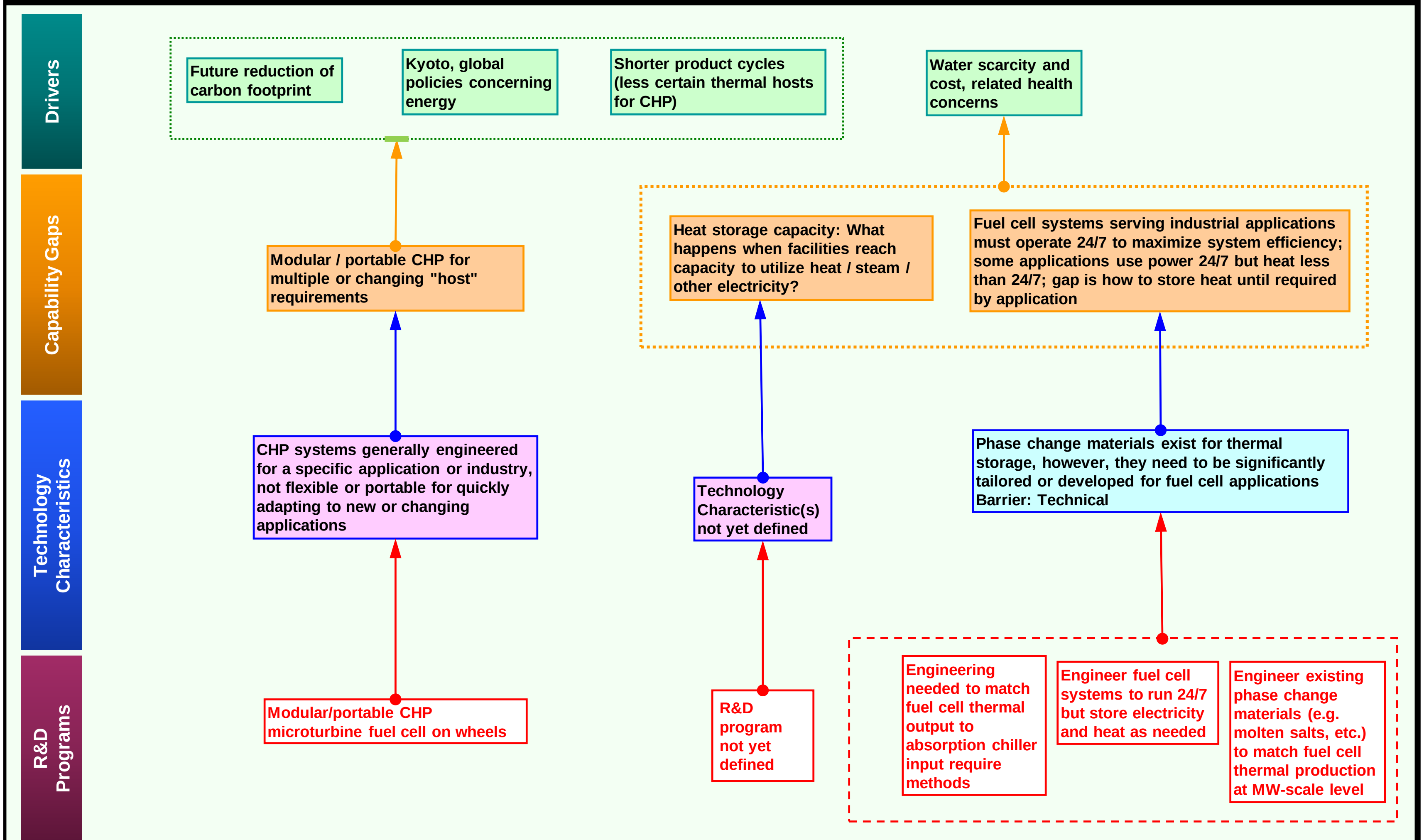
Combined Heat and Power (CHP)

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Delivery (6 of 8)

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Engineer existing phase change materials (e.g. molten salts, etc.) to match fuel cell thermal production at MW-scale level. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Engineer fuel cell systems to run 24/7 but store electricity and heat as needed. Engineer fuel cell systems to run 24/7 (to maximize efficiency), but store electricity and heat as needed when on-site applications do not require electricity or heat or both

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Engineering needed to match fuel cell thermal output to absorption chiller input require methods. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Modular / portable CHP microturbine fuel cell on wheels. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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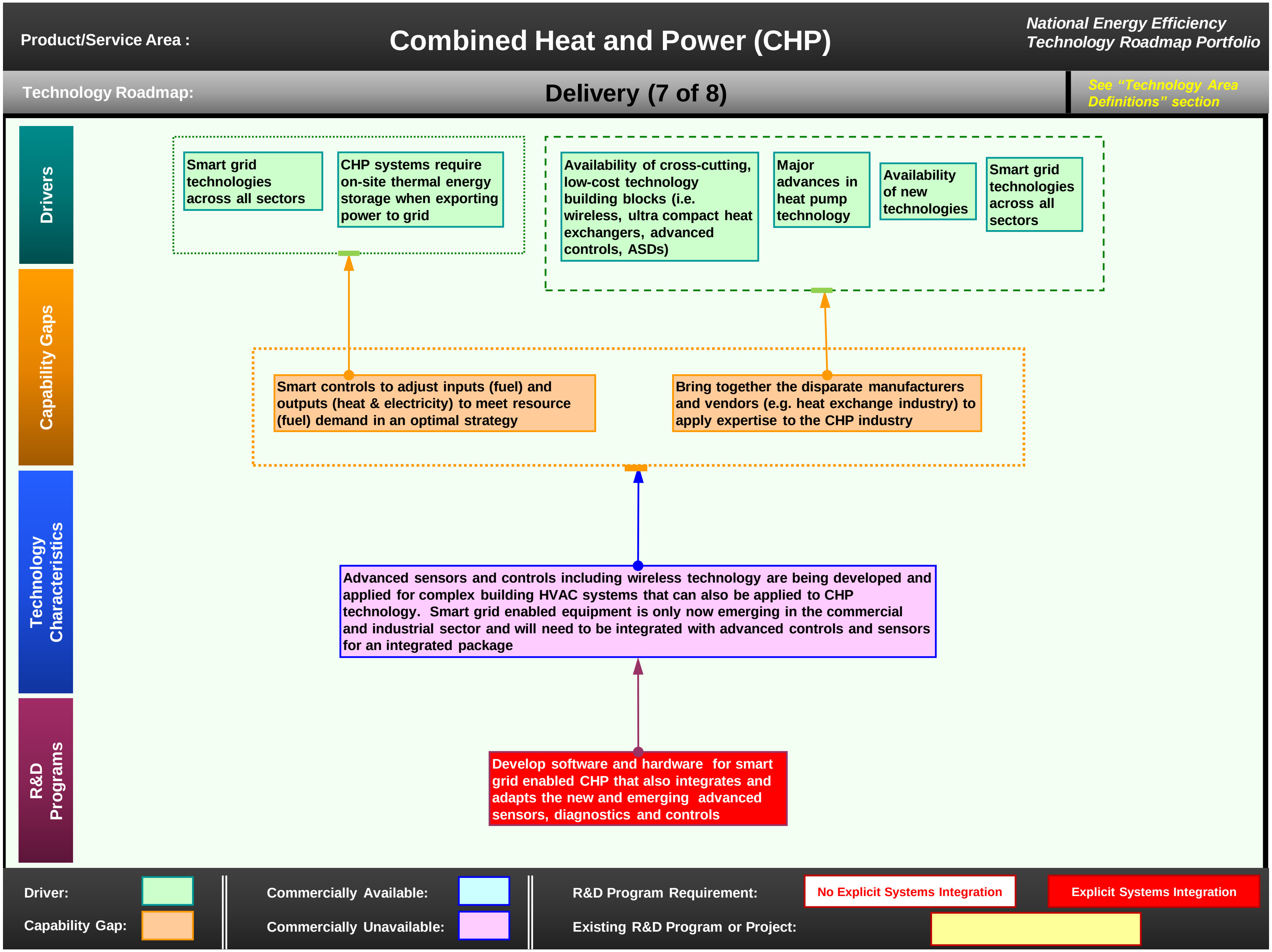
Product/Service Area :
Combined Heat and Power (CHP)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Delivery (7 of 8)
See "Technology Area Definitions" section
Drivers
Smart grid technologies across all sectors
CHP systems require on-site thermal energy storage when exporting power to grid
Availability of cross-cutting, low-cost technology building blocks (i.e. wireless, ultra compact heat exchangers, advanced controls, ASDs)
Major advances in heat pump technology
Availability of new technologies
Smart grid technologies across all sectors
Capability Gaps
Smart controls to adjust inputs (fuel) and outputs (heat & electricity) to meet resource (fuel) demand in an optimal strategy
Bring together the disparate manufacturers and vendors (e.g. heat exchange industry) to apply expertise to the CHP industry
Technology Characteristics
Advanced sensors and controls including wireless technology are being developed and applied for complex building HVAC systems that can also be applied to CHP technology. Smart grid enabled equipment is only now emerging in the commercial and industrial sector and will need to be integrated with advanced controls and sensors for an integrated package
R&D Programs
Develop software and hardware for smart grid enabled CHP that also integrates and adapts the new and emerging advanced sensors, diagnostics and controls
Driver:
Capability Gap:
Commercially Available:
Commercially Unavailable:
R&D Program Requirement:
No Explicit Systems Integration
Explicit Systems Integration
Existing R&D Program or Project:

R&D Program Summaries

Develop software and hardware for smart grid-enabled CHP that integrates and adapts new and emerging advanced sensors, diagnostics, and controls. Develop software and hardware systems for CHP that is similar to advanced sensors, diagnostics and controls currently found in the HVAC industry for fans, pumps, motors, valves, etc.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

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Product/Service Area :

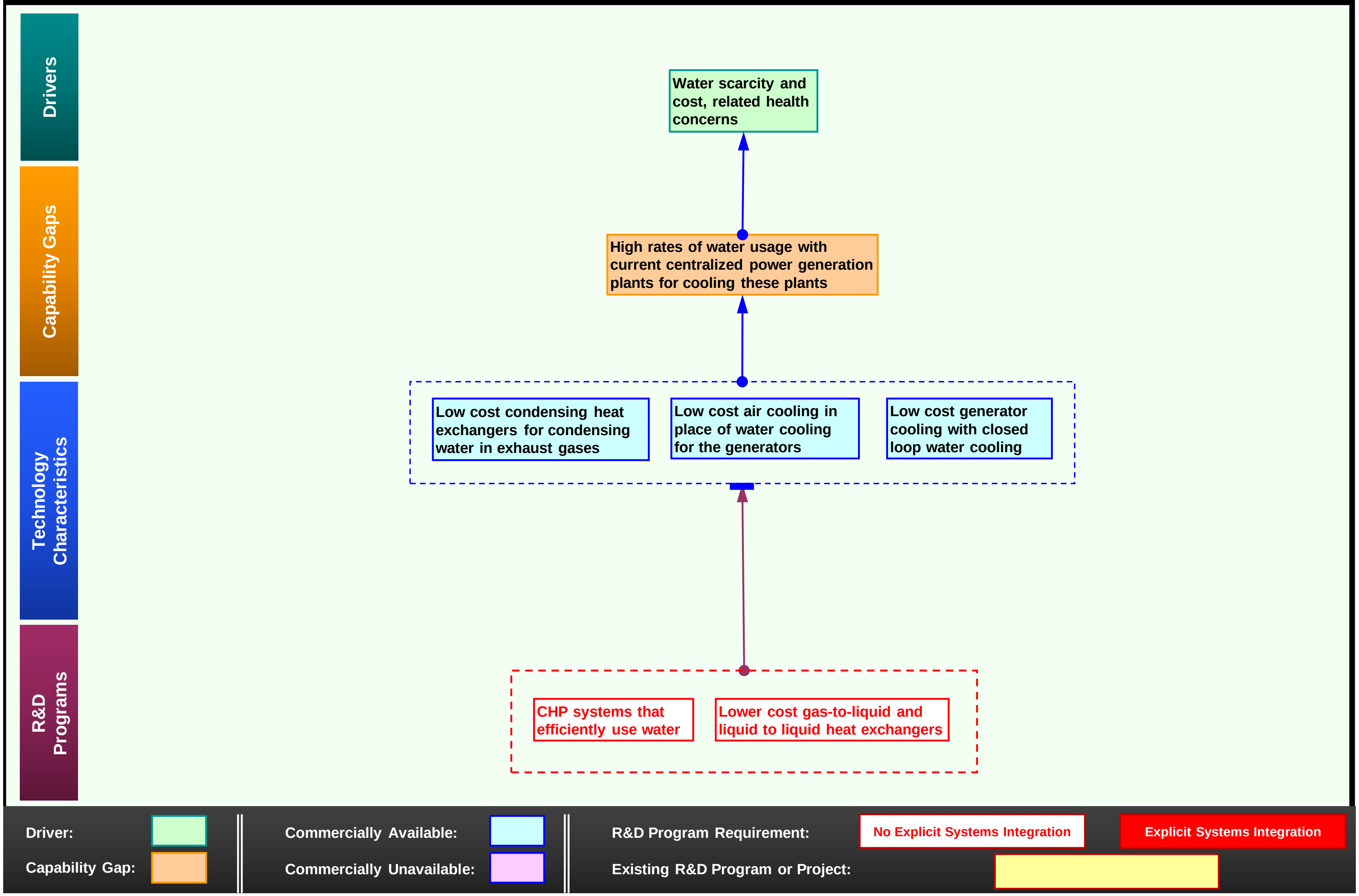
Combined Heat and Power (CHP)

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Delivery (8 of 8)

See "Technology Area Definitions" section



R&D Program Summaries

CHP systems that use water efficiently. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Lower cost gas-to-liquid and liquid to liquid heat exchangers.
(Summary not yet provided.)

Existing research: None identified.

Key research questions:

2. Questions not yet specified

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