Torrefaction

A Pathway Towards Fungible Biomass Feedstocks?

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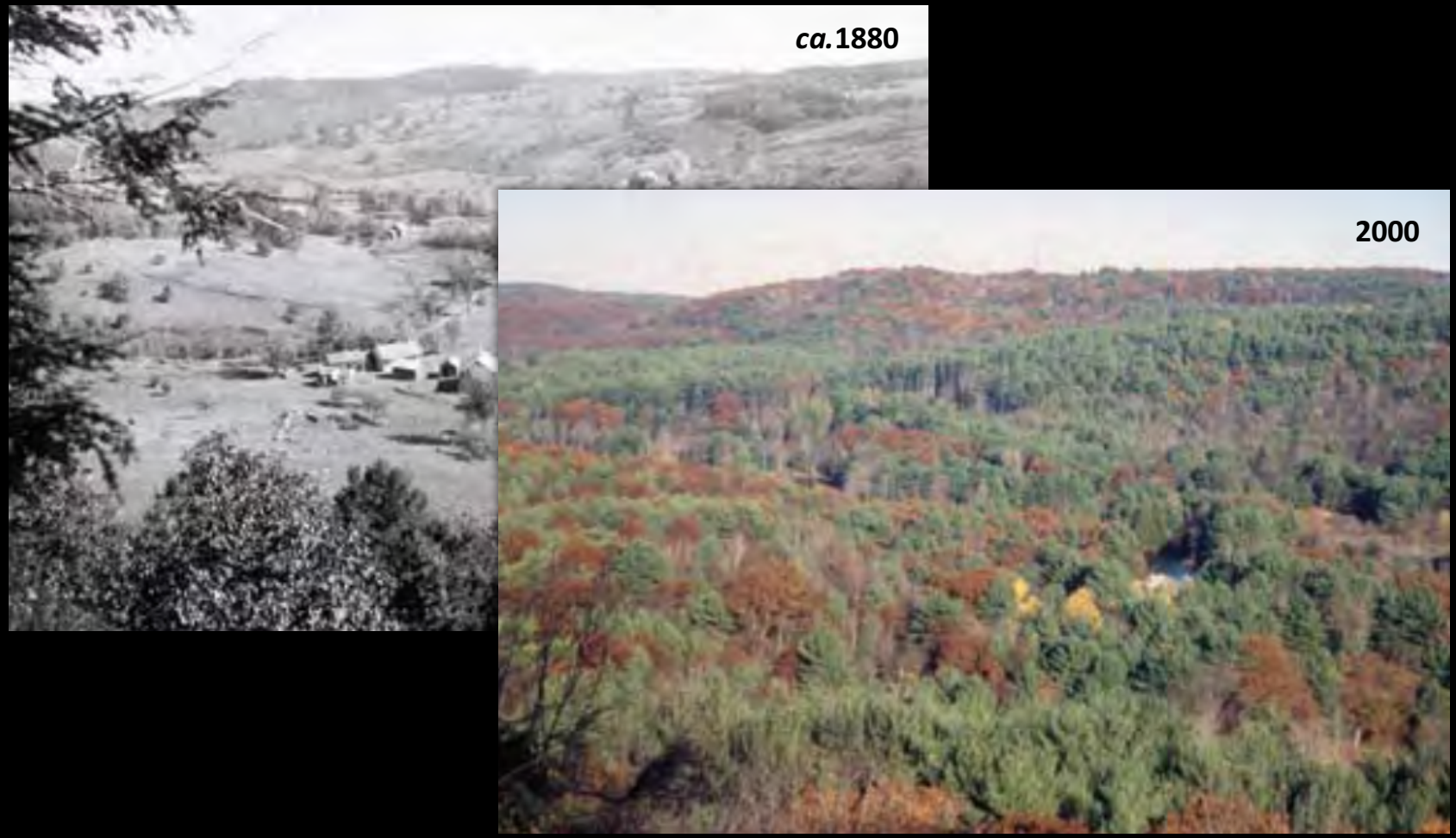
Bioeconomy Hurdles

- Producing and accessing **sustainable and affordable feedstocks**
- **Cost-competitive** conversion technologies
- Optimizing distribution infrastructure
- Educating the consumer

Source: *Federal Activities Report on the Bioeconomy,* 2016

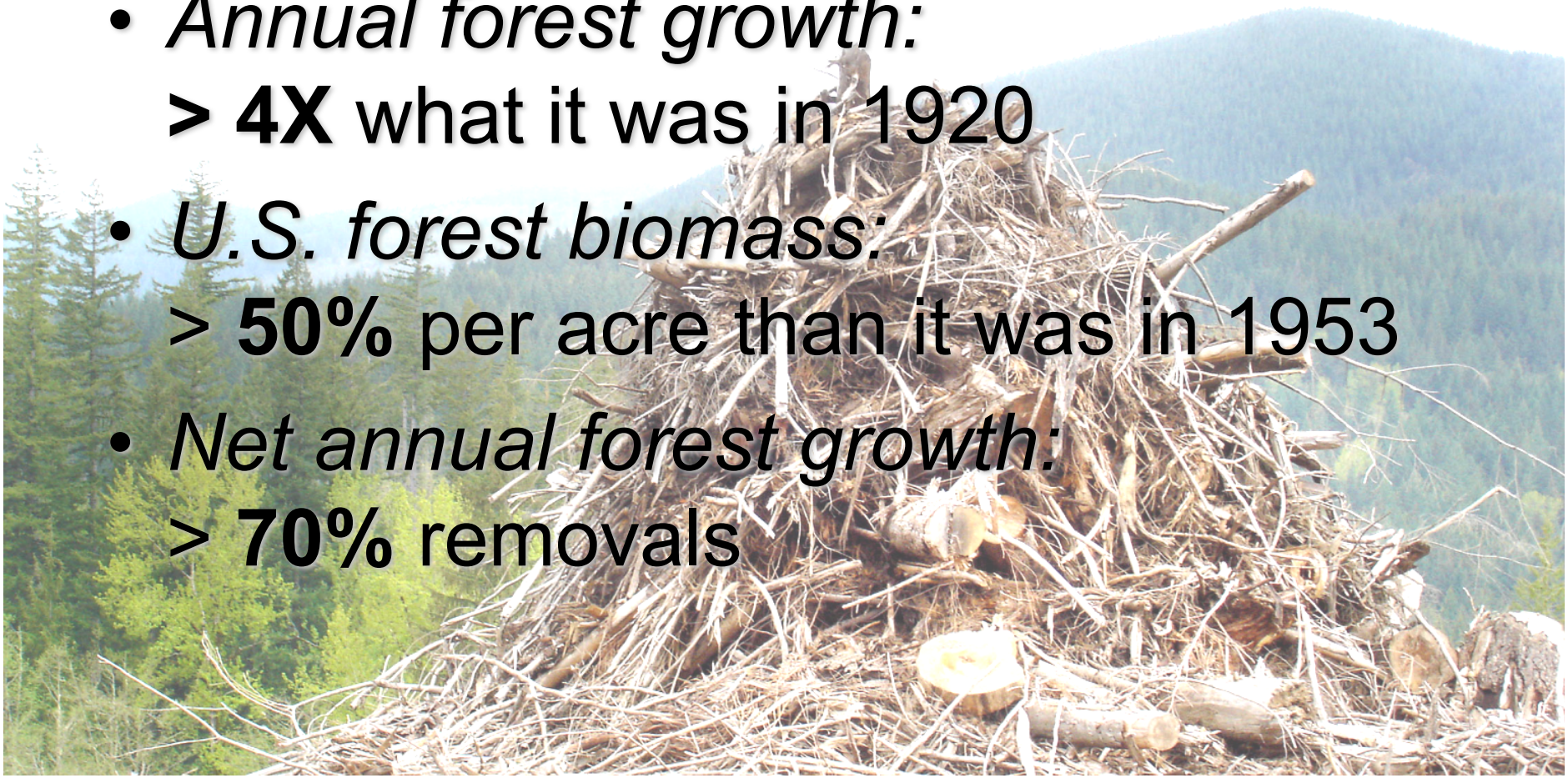
Forest Resources



SOURCE: *Forest Resources of the United States—2007,* USDA.

Forest Resources

- *Annual forest growth:*
  > 4X what it was in 1920
- *U.S. forest biomass:*
  > **50%** per acre than it was in 1953
- *Net annual forest growth:*
  > **70%** removals



SOURCE: *Forest Resources of the United States—2007,* USDA.

How Much?

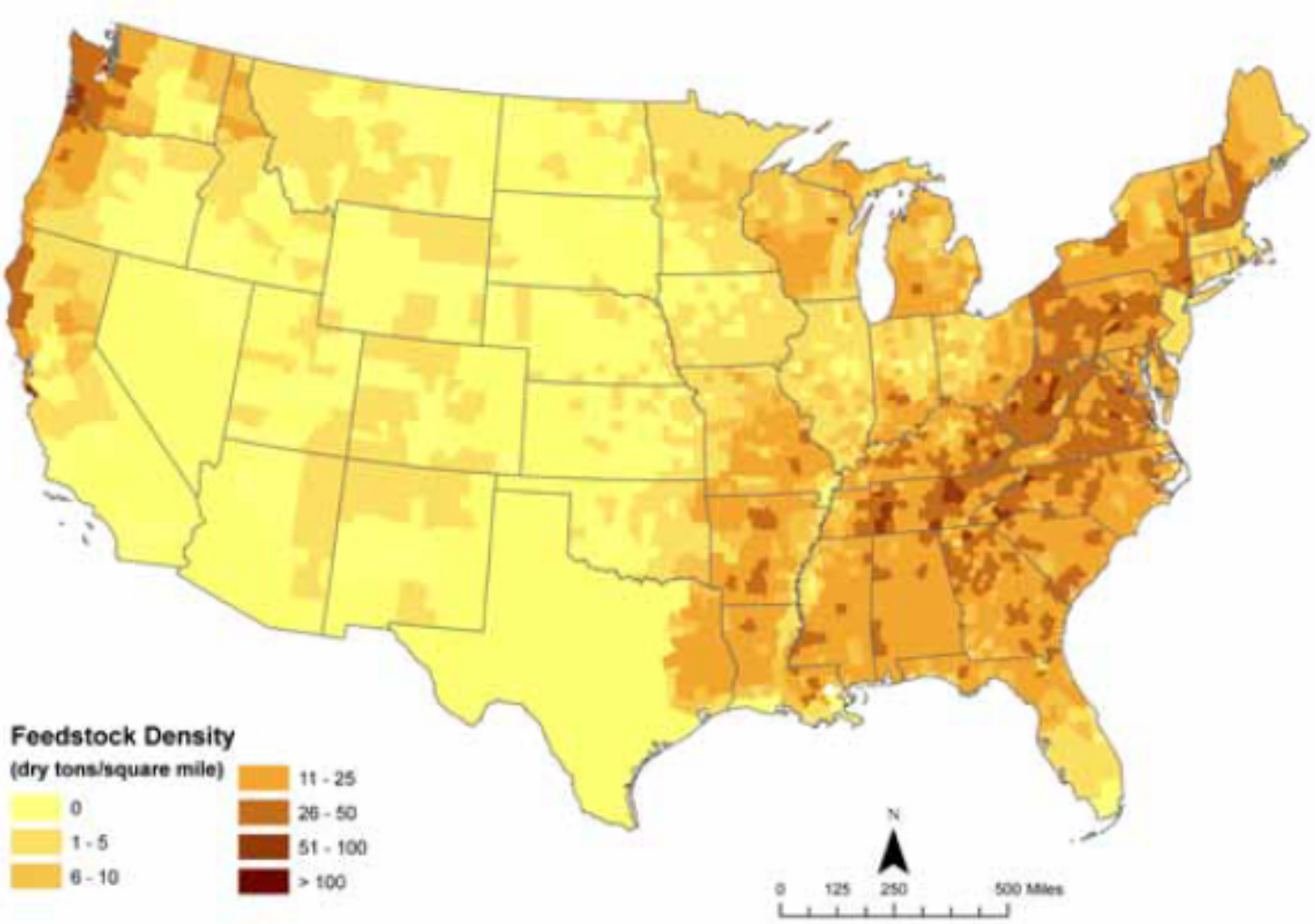
- Annual harvest: 320 million dry tons
- Roundwood: 227 million dry tons
- Residues: 68 million dry tons

*"Most of this residue is left onsite because its small piece size makes it **unsuitable and uneconomic** for the manufacturing of forest products."*

Source: U.S. Billion-Ton Update, US DOE, 2011.

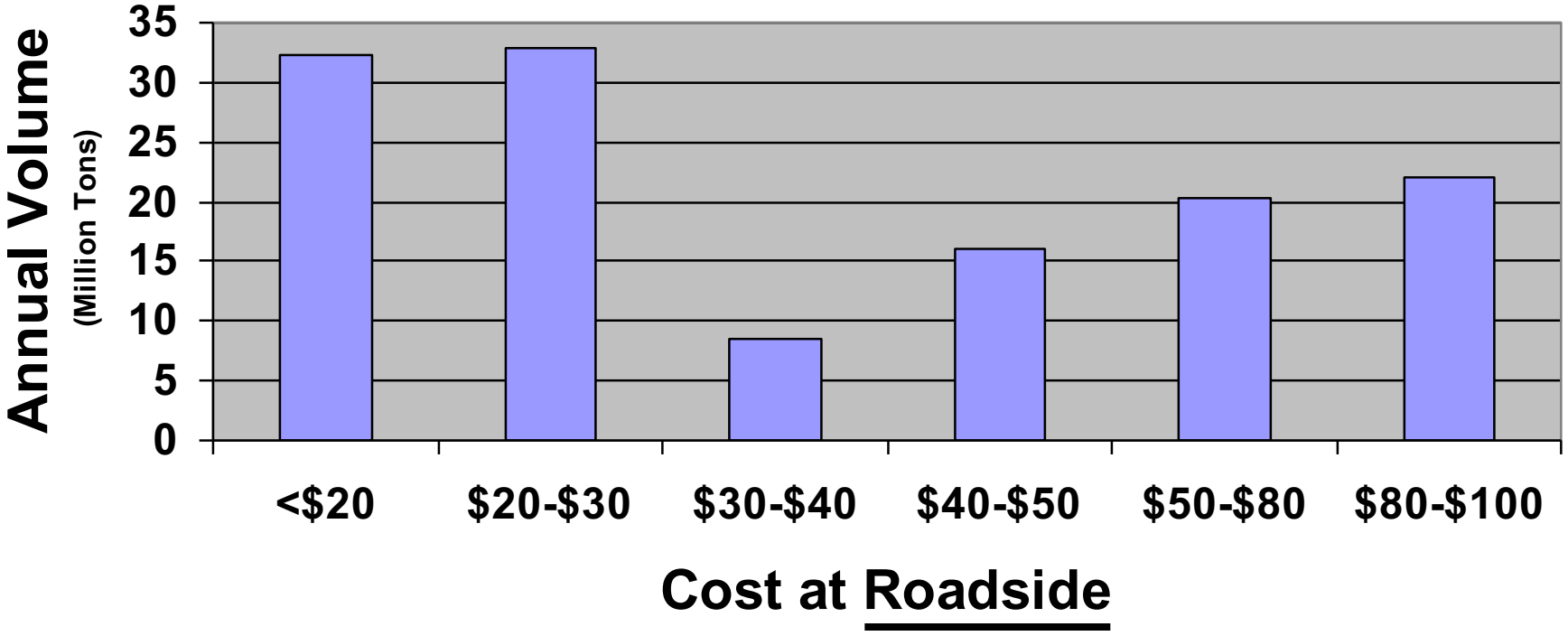
Cost?

$60 per dry ton



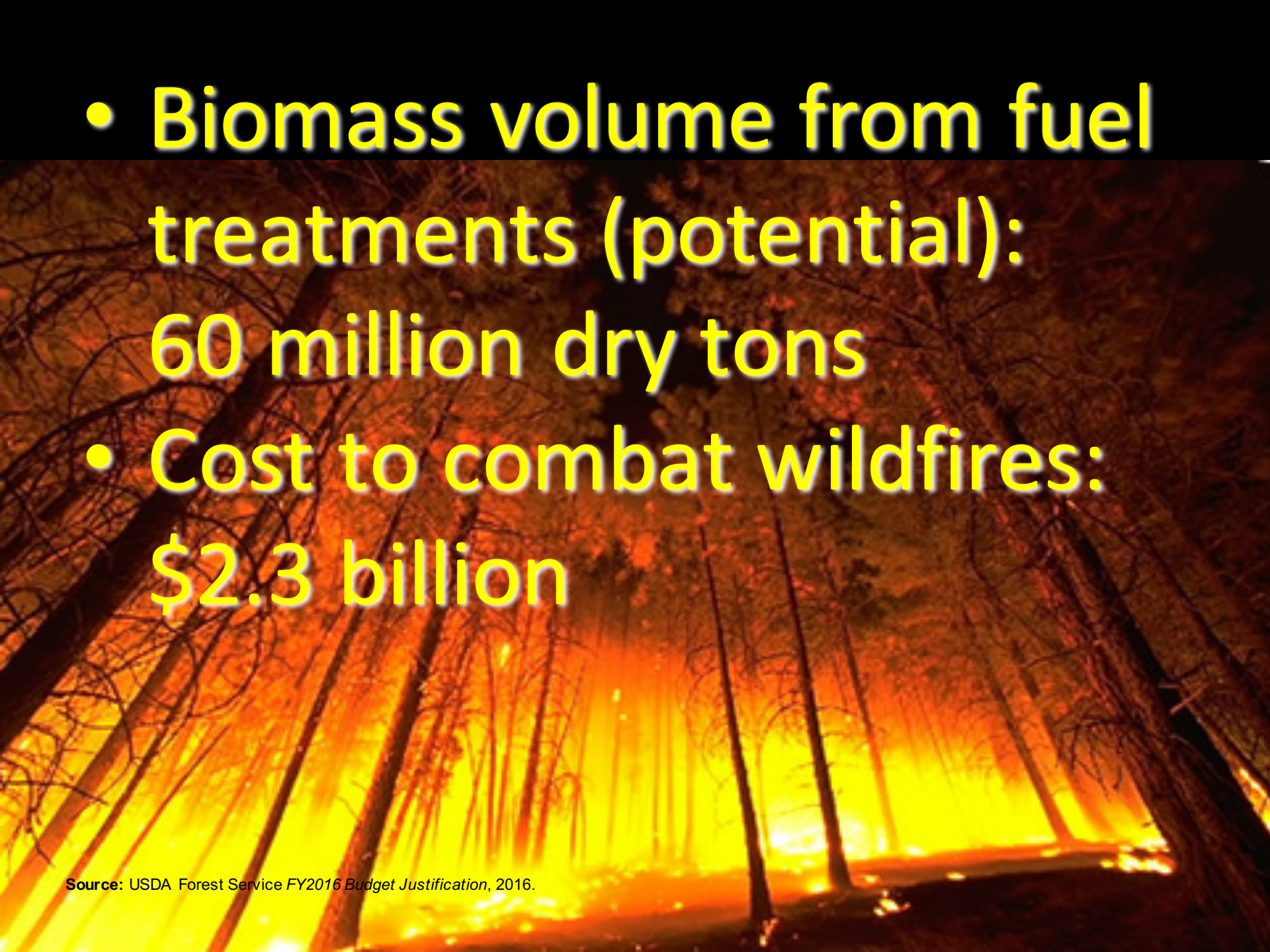
Source: *Spatial distribution of simulated forest residue thinnings at $60 per dry ton* U.S. Billion-Ton Update, US DOE, 2011.

Cost of Forest Biomass



Source: U.S. Billion-Ton Update, US DOE, 2011.

- Biomass volume from fuel treatments (potential): 60 million dry tons
- Cost to combat wildfires: $2.3 billion



Source: USDA Forest Service *FY2016 Budget Justification*, 2016.

Current Situation

Low-cost forest biomass is available!

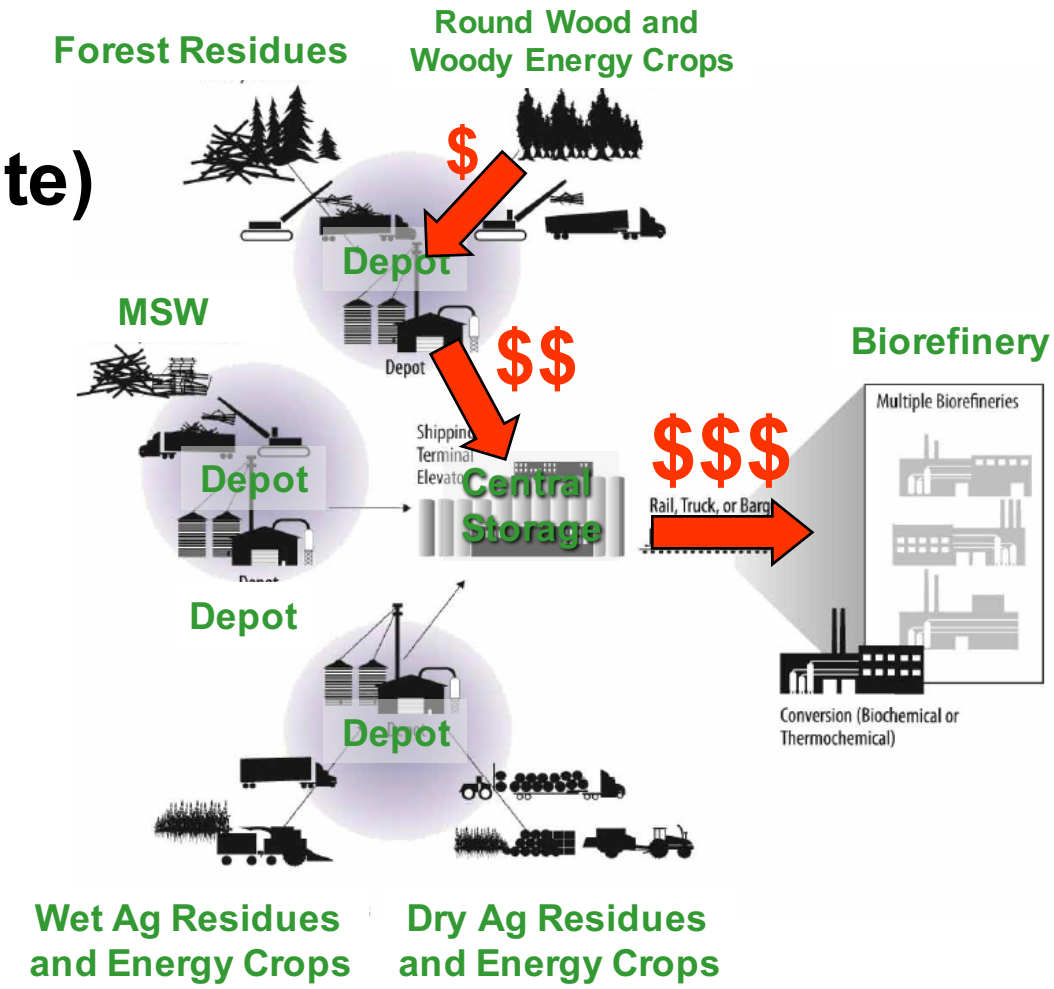
How do we expand its use as a bioenergy carrier and a feedstock for biorefineries?

Challenges

Cost
(at Biorefinery Gate)

- Handling
- Transportation
- Storage

Heterogeneity



Source: DOE Bioenergy Technologies Office, 2016.

But …

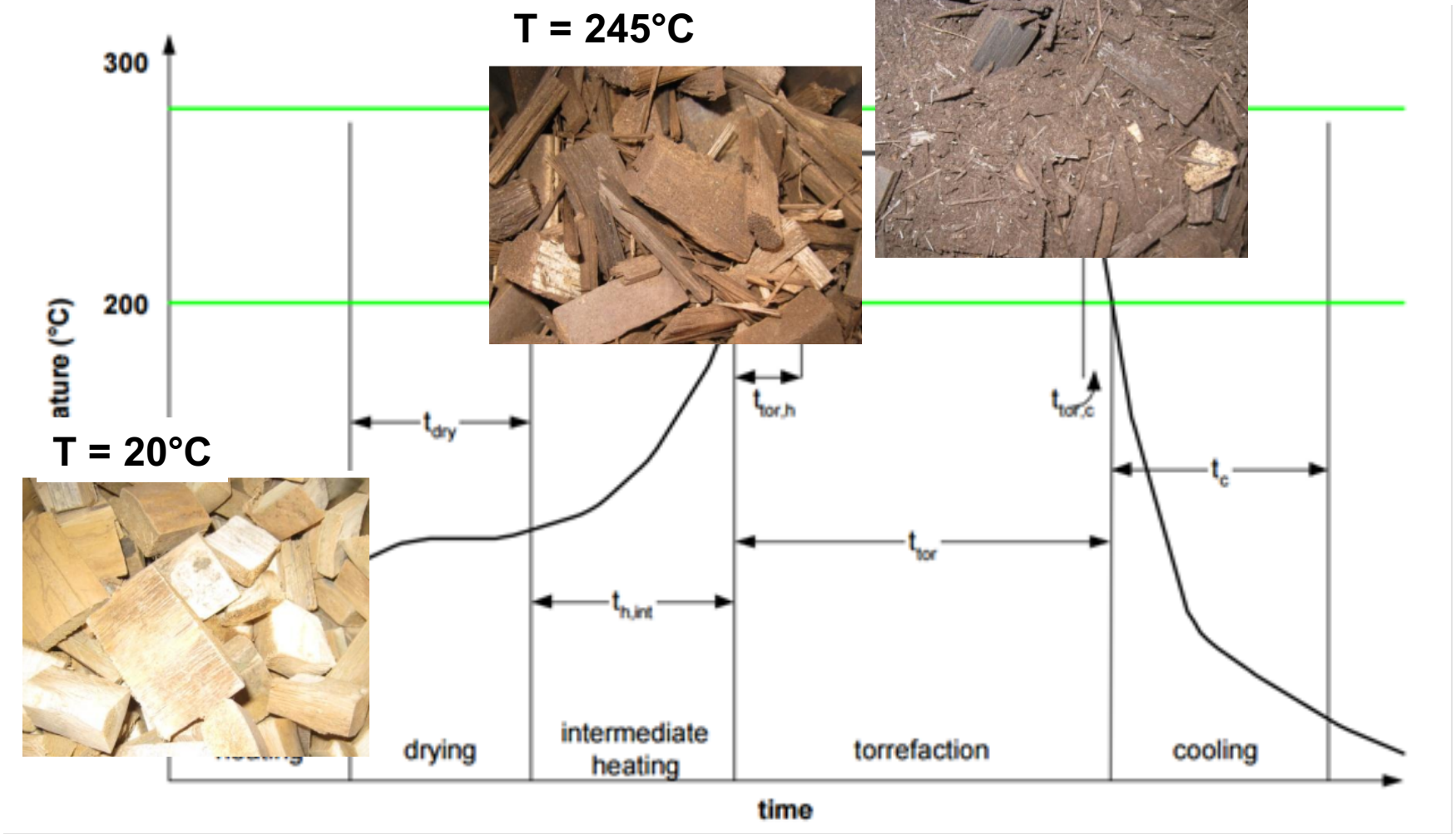
- Energy (wood) pellet industry is growing*:
  - 4.6 million ton export market (2015)
  - 9.7 million (2020)
- Sets an effective price floor for woody biomass
- RINs cannot compete!

***Source:** RISI, 2016.

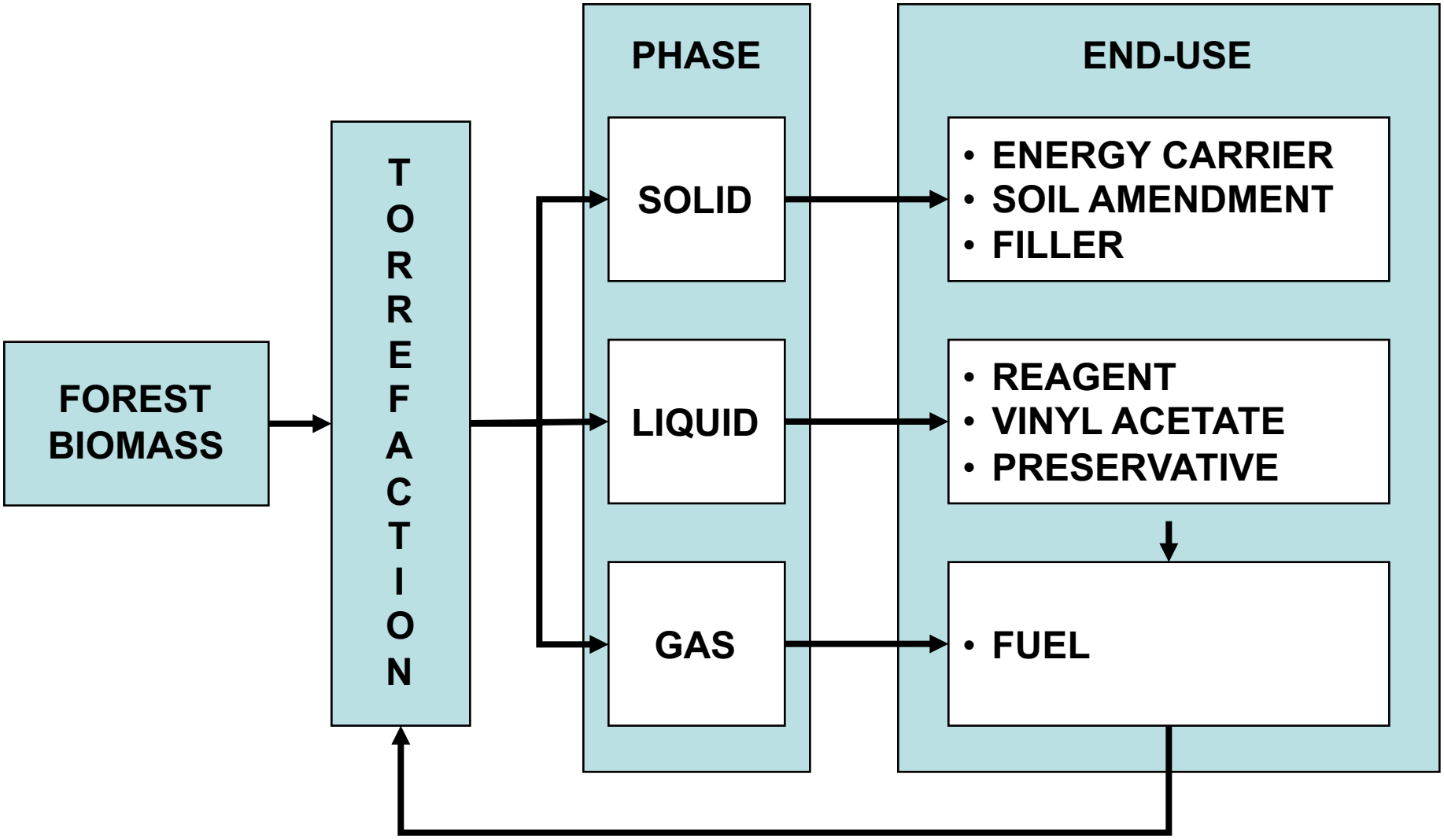
Torrefaction

- Mild pyrolysis: *Reaction in an absence of oxygen*
- Atmospheric
- Typical process temperatures: 200-300°C

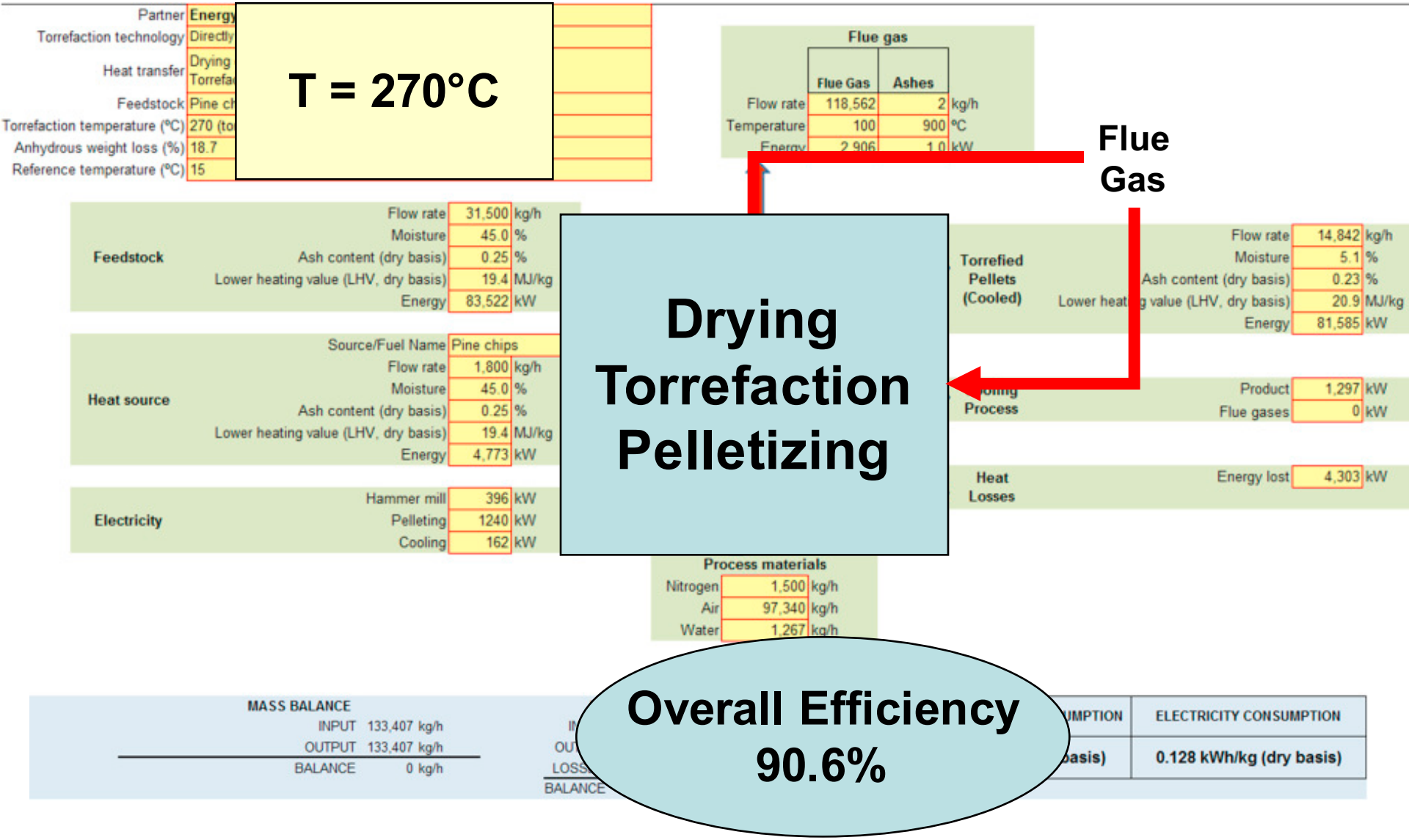
Kinetics



Sources: Bergman *et al.* 2005.



Source: ANL Consultants LLC, adapted from M. Hoeft 2013.



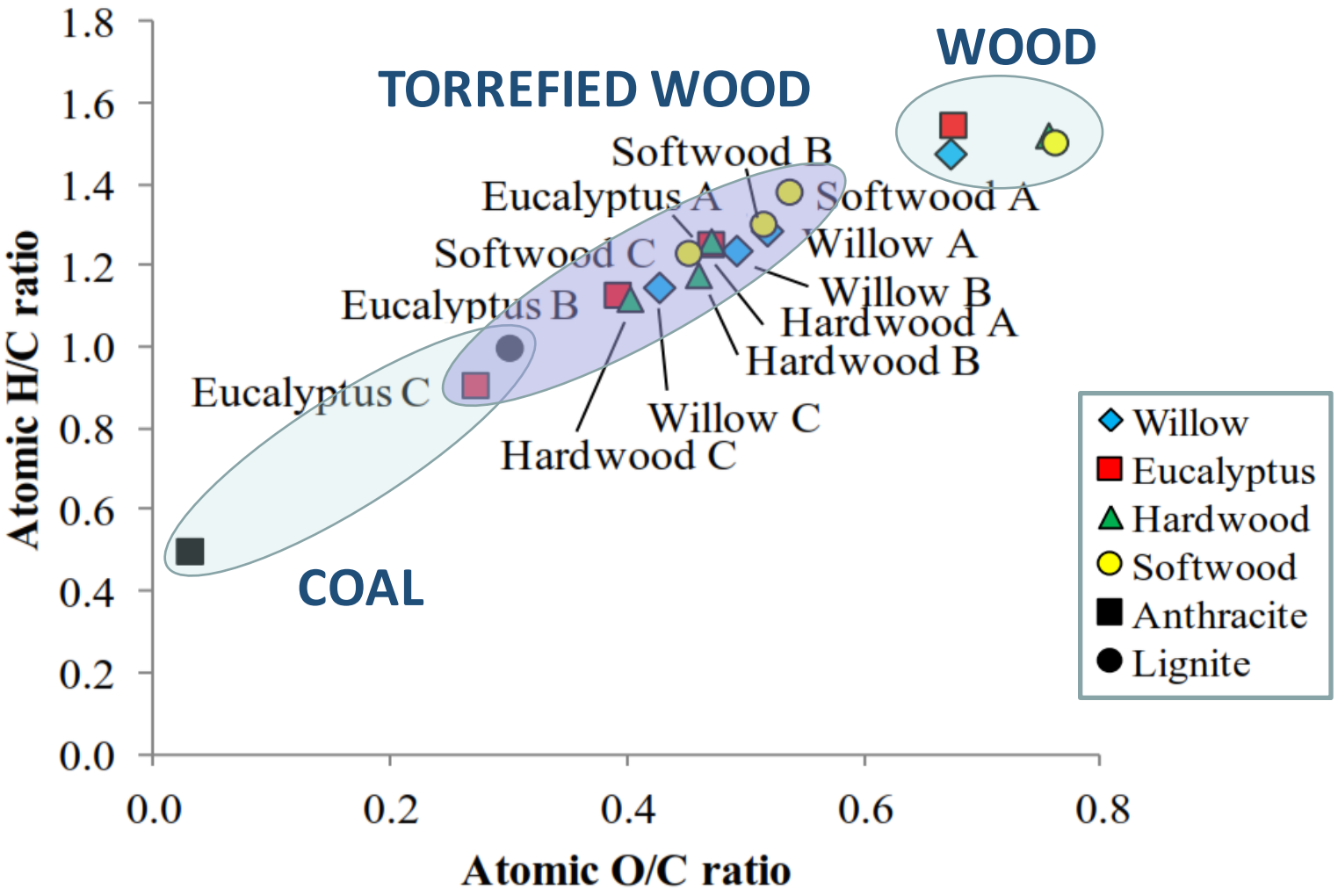
Source: Thran *et al.* 2016.

Energy Density

Material	Bulk Density (kg/m^3)	Energy Density (GJ/m^3)
Wood	400	6.5
Pelletized	700	**10.7**
Torrefied Wood	300	7.5
Pelletized	700	**16.0**
PRB Coal	850	**18.0**

Sources: Handbook of Clean Energy Systems, 2015; IEA Task 40, 2016

Comparison to Coal

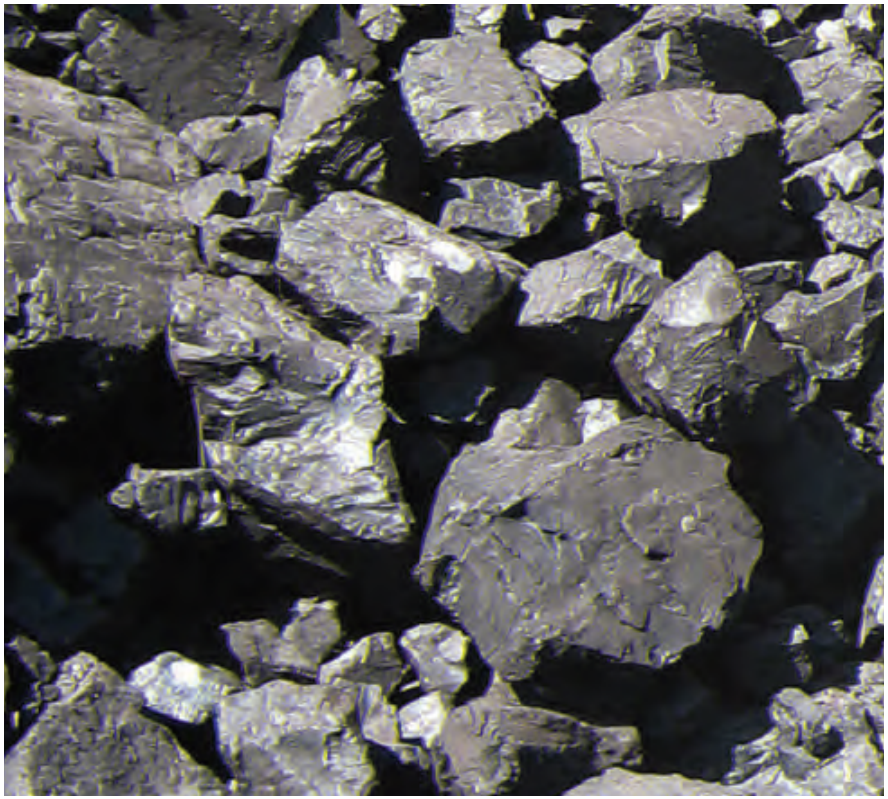


Source: R. Ibrahim, *Fundamentals of torrefaction of biomass and its environmental impacts,* 2013.

Advanced Bioenergy Carrier

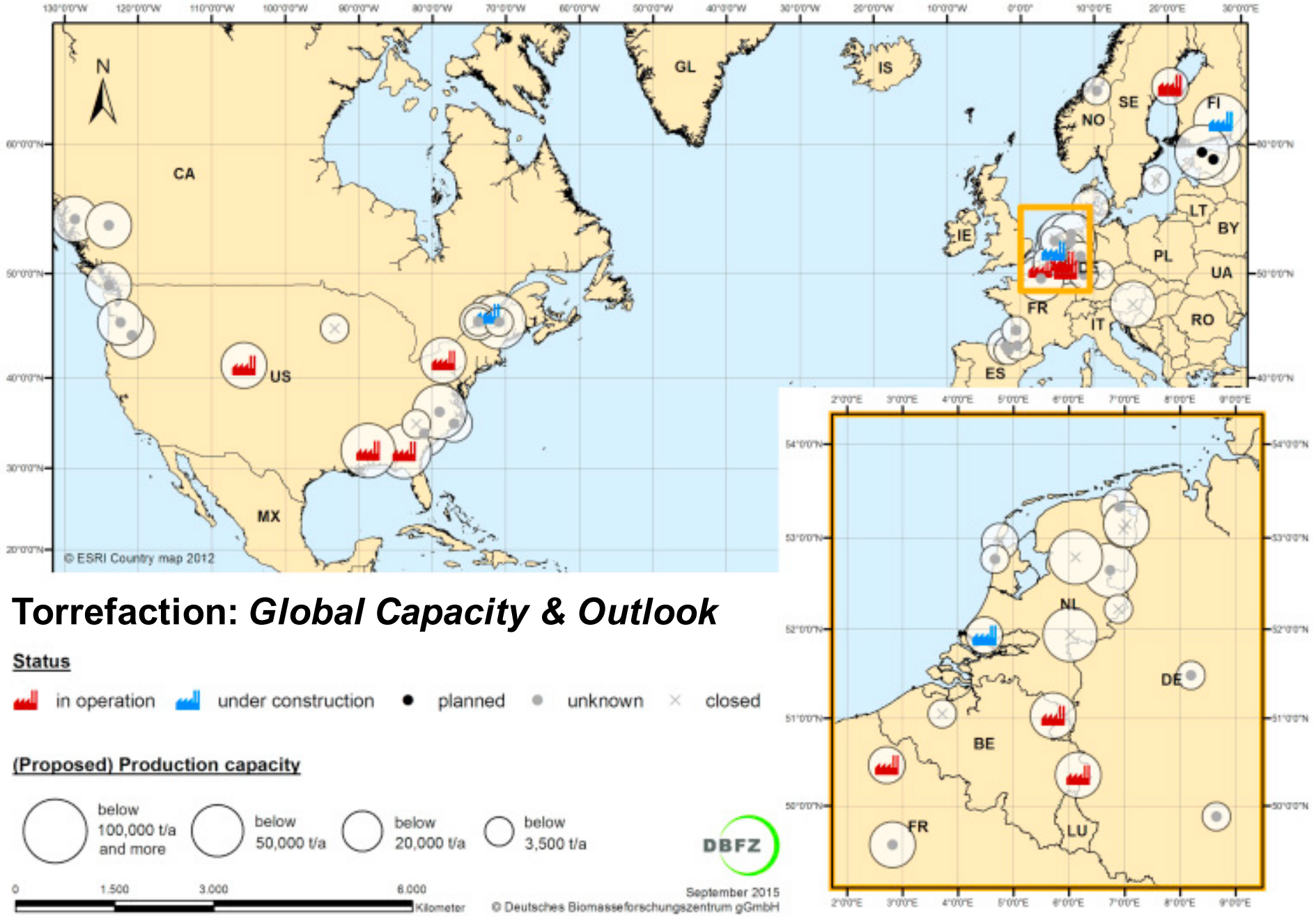
- High energy density
- Low sulfur
- Low ash
- Friable
- Homogeneous

  and …



Water Resistant!

Source: IEA 2016.



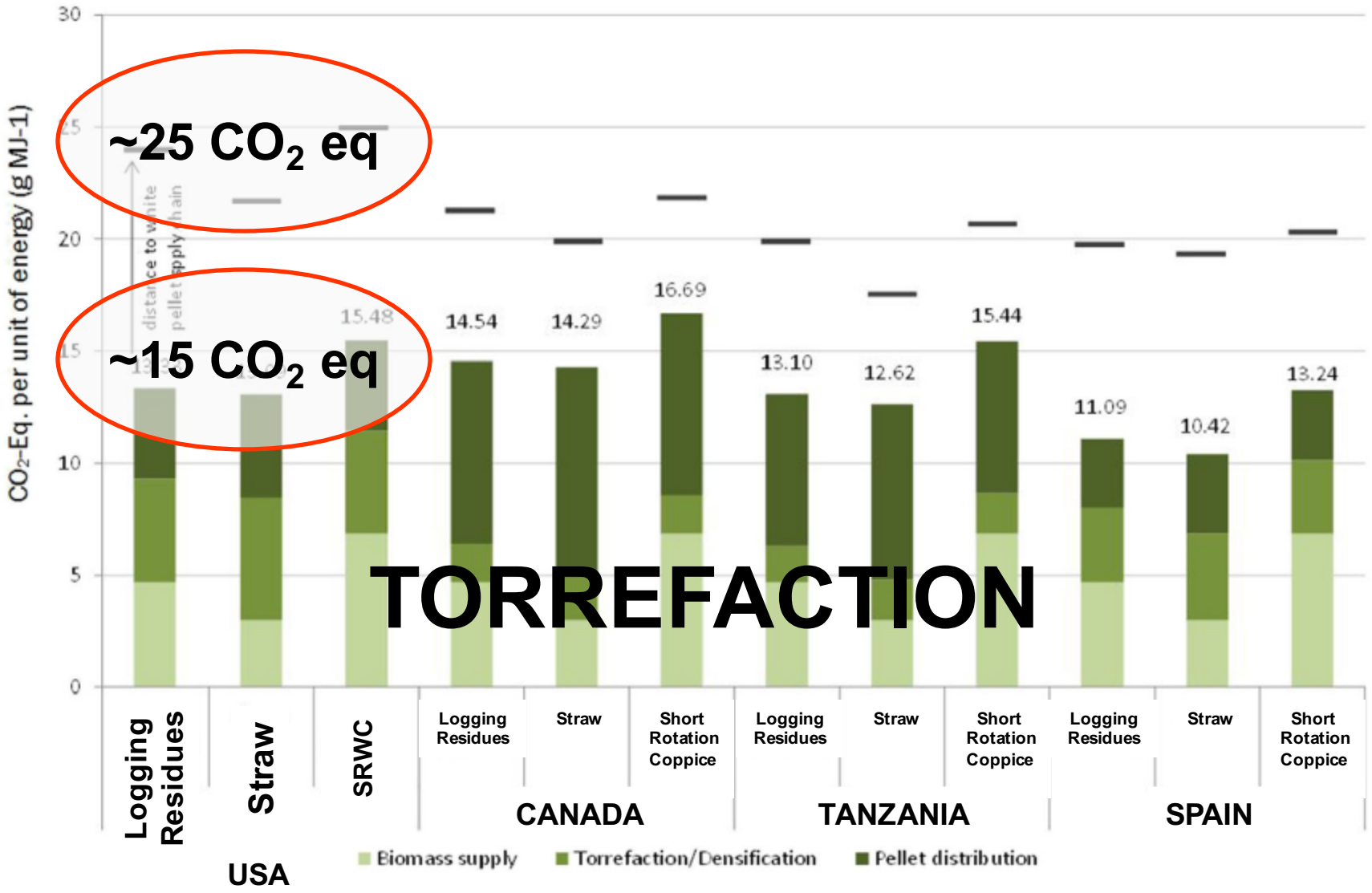
Torrefaction: *Global Capacity & Outlook*

Source: Thran *et al.* 2016.

Drivers

- Dispatchable, base load power generation
- GHG reduction and compliance

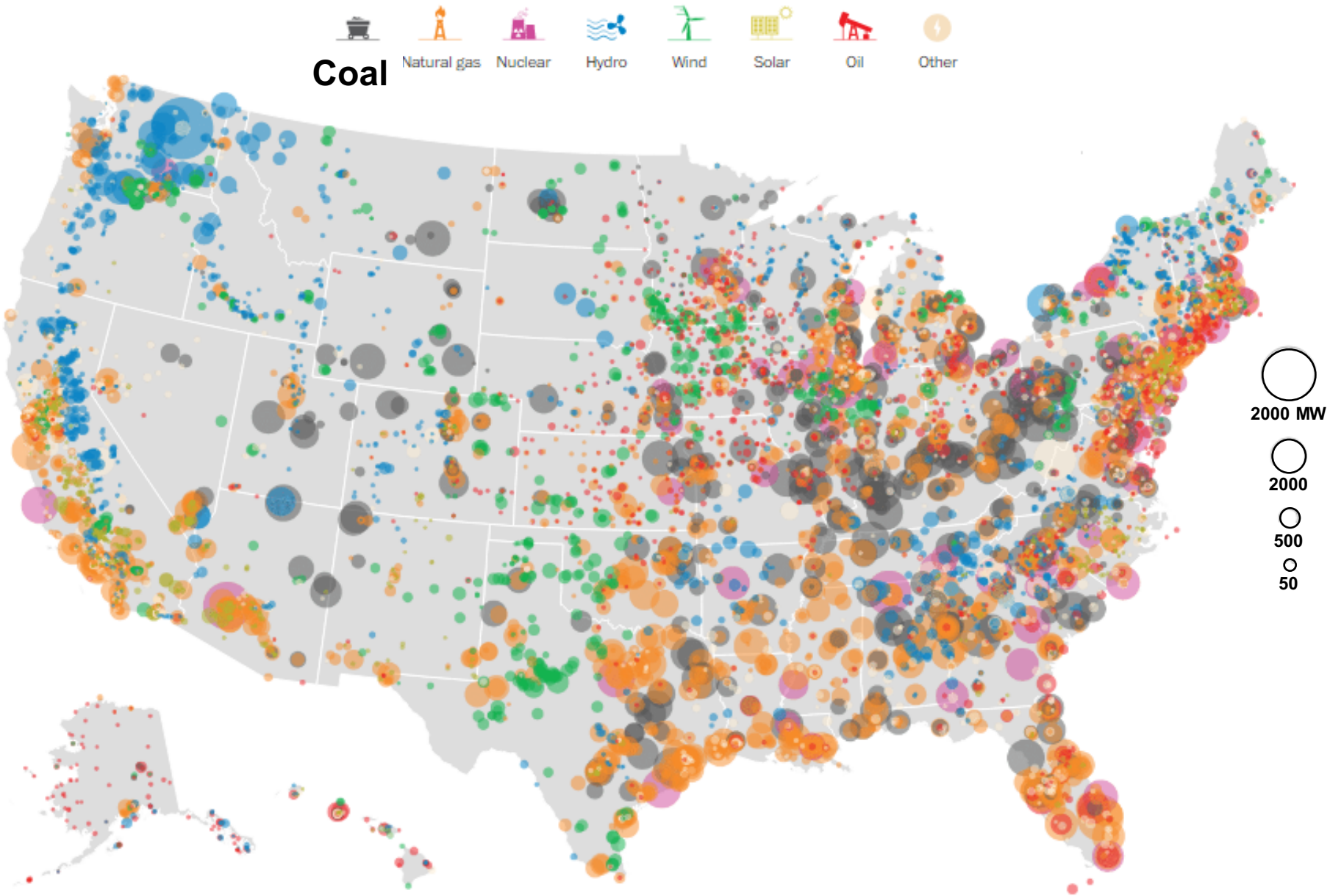
Greenhouse Gas Emissions



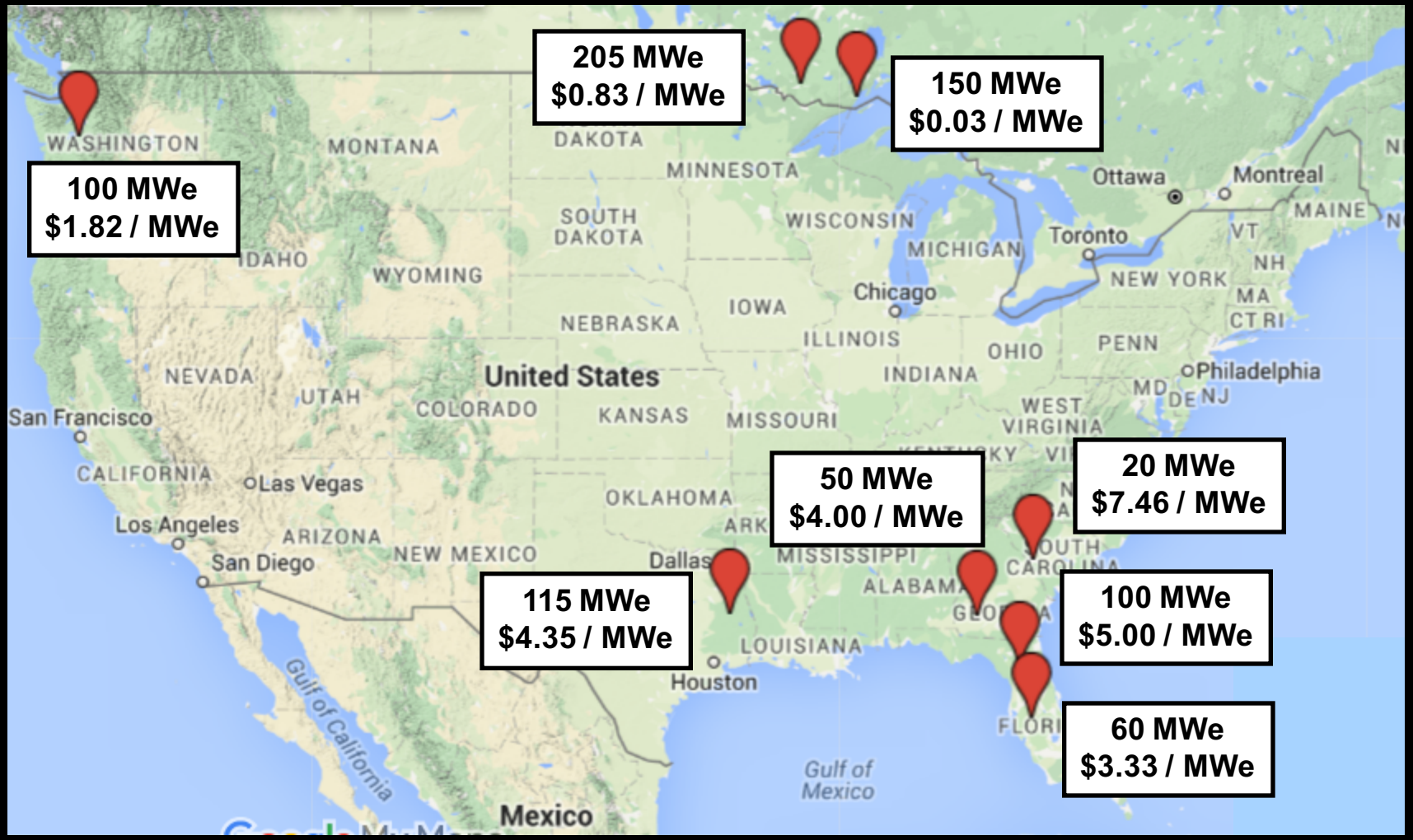
Source: Thran *et al.* 2016.

Drivers

- Dispatchable, base load power generation
- GHG reduction and compliance
- Capital avoidance



Source: Washington Post, 2015.



Source: ANL Consultants LLC

ONTARIO POWER GENERATION

Thermal power

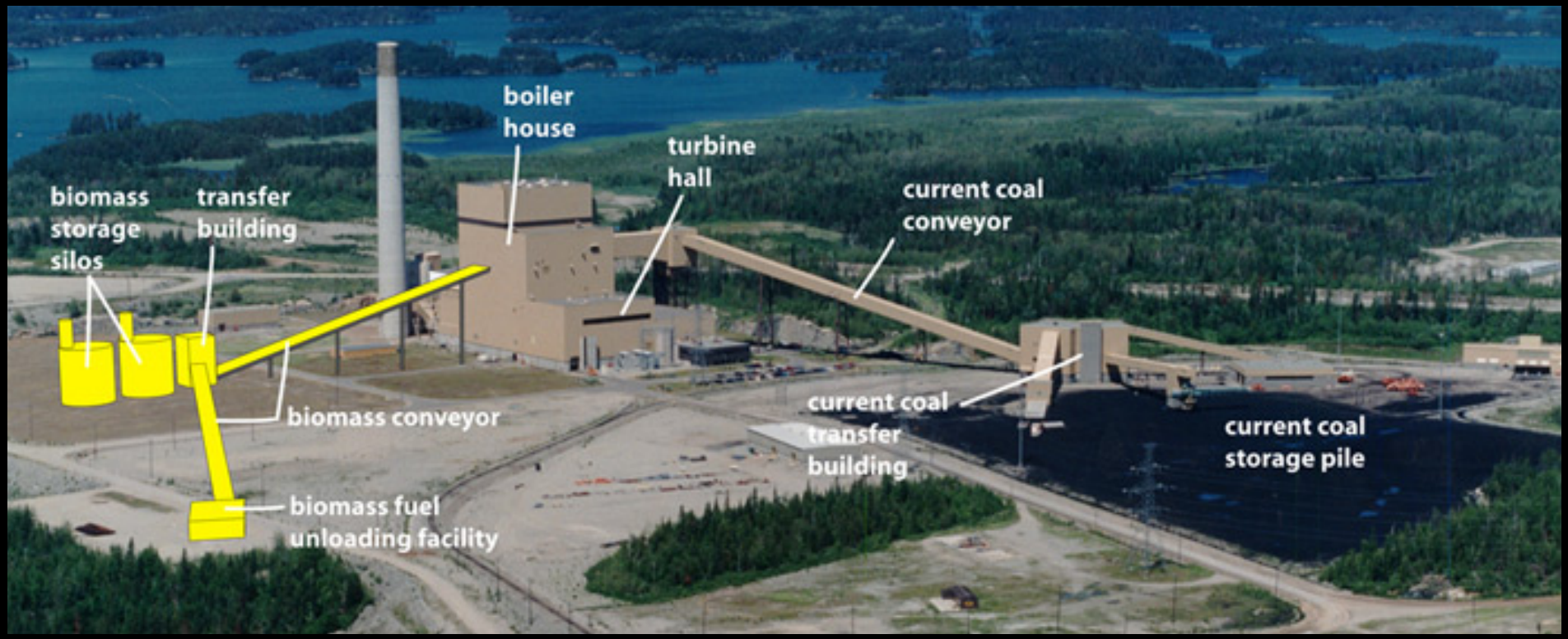
In April of 2014, Ontario Power Generation burned its last piece of coal to generate electricity in Ontario. This move off coal was North America's single largest climate change initiative and the equivalent of taking seven million cars off the road. This made Ontario the first jurisdiction in North America to fully eliminate coal as a source of electricity generation.

OPG CORPORATE PROFILE

Case Study

Case No. 1: *Atikokan Generating Station*

- 205 MW
- Converted to 100% white wood pellets
- Cost: $170 million



Source: Ontario Power Generation (OPG), 2016.

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Case Study

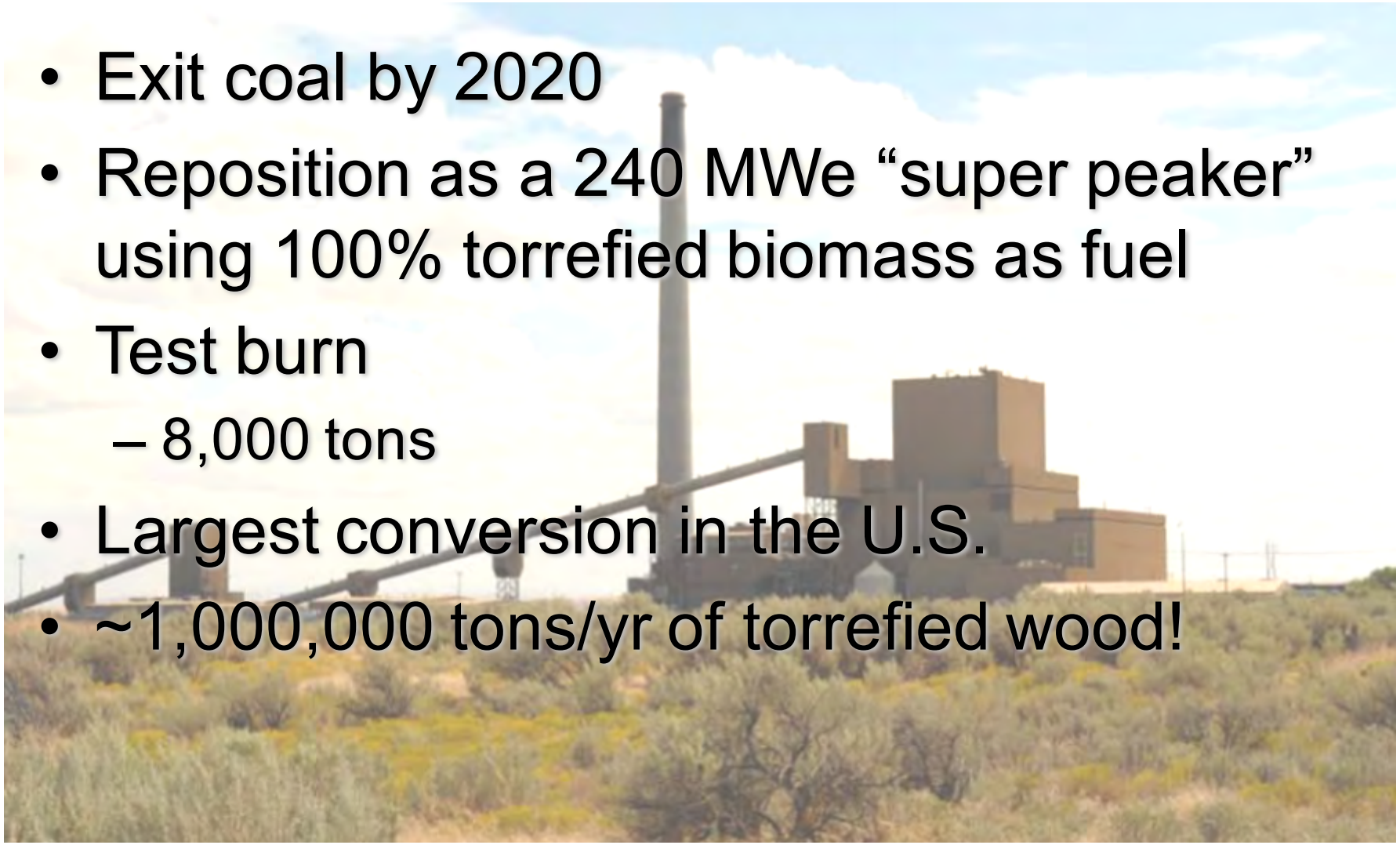
Case No. 1: Atikokan Generating Station

- 205 MW
- Converted to 100% white wood pellets
- Cost: $170 million

Case No. 2: Thunder Bay Generating Station

- 150 MW
- Coal conversion to “advanced biomass”
- Cost: $5 million

PGE



- Exit coal by 2020
- Reposition as a 240 MWe “super peaker” using 100% torrefied biomass as fuel
- Test burn
  - 8,000 tons
- Largest conversion in the U.S.
- ~1,000,000 tons/yr of torrefied wood!

Source: PGE *2016 Integrated Resource Plan,* May 2016.

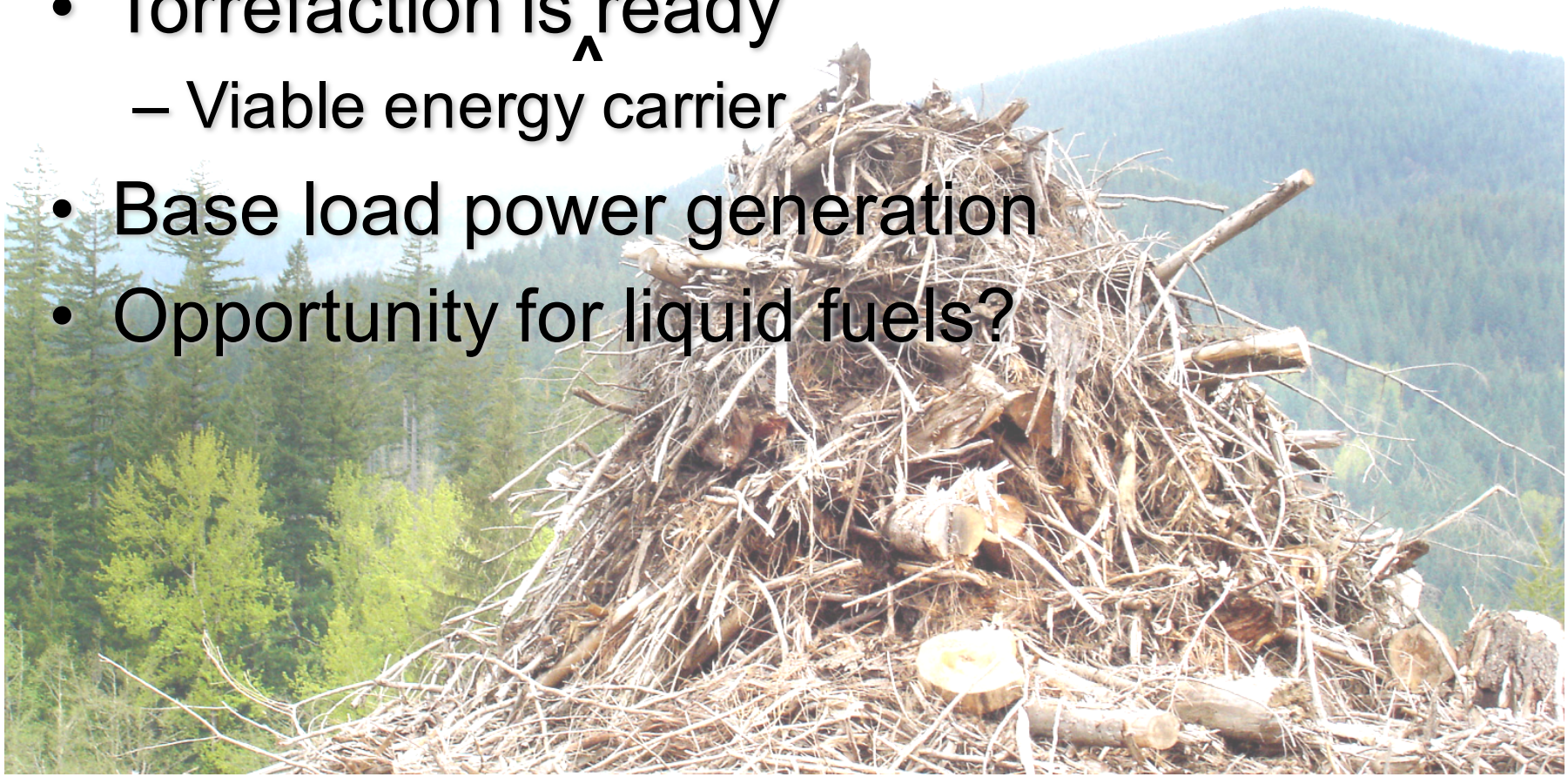
Co-Firing

- Blended with coal and co-fired
- "Drop-in"
- "All the above" strategy to complete phase-out of coal?

Photo Source: ***Phys Org,*** 2014.

Conclusions

- Torrefaction is almost ready
  - Viable energy carrier
- Base load power generation
- Opportunity for liquid fuels?



Thank You!

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