Effects of Diluted Bitumen on Crude Oil Transmission Pipelines

Committee for a Study of Pipeline Transportation of Diluted Bitumen

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

PHMSA contracted with National Academies to convene an expert committee to:

- **Analyze whether transportation of diluted bitumen by transmission pipeline has an increased likelihood of release compared with pipeline transportation of other crude oils.**

- **If an increased likelihood of release is found:**

  --review the federal hazardous liquid pipeline safety regulations to determine whether they are sufficient to mitigate the increased likelihood of release.

Study Limits

- **“Risk” assessment requires understanding of likelihood and consequences.**
- **Our focus is on the likelihood of release, per request of PHMSA.**
- **Study committee appointed on the basis of expertise relevant to likelihood of release.**
- **No consideration given to the consequences of diluted bitumen releases or whether a study of consequences is warranted.**

Study Scope

- **Key Terms in Work Statement:**
  - **Focus on likelihood of release, not consequences**
  - **Focus on transmission pipelines**
  - **Compare shipments of diluted bitumen to shipments of "other crudes" transported by pipeline**

- **<u>Basic question</u>: Do shipments of diluted bitumen differ sufficiently from shipments of other crude oils in such a way as to increase the likelihood of releases from transmission pipelines?**

What is bitumen?

- Form of petroleum with high density and viscosity, recovered from Western Canadian oil sands.
- Bitumen imports are extracted in situ, using steam-assisted drilling techniques. Mined bitumen is upgraded in Canada and not piped to U.S.
- Bitumen will not flow in unheated pipelines unless diluted with light oils.
- Diluents consist of distillates and light oils, using dilution ratios of 25% to 50%.
- Diluted bitumen imports are transported in thousands of miles of U.S. pipeline.

Analytic Approach

1. **Review data on pipeline incidents** in U.S. and Canada to:
   - examine release characteristics and causes from agencies' records.
   - look for real cases in which shipments of specific crude types, including diluted bitumen, have been associated with release causes because of their specific physical and chemical properties.
2. **Identify the known ways in which specific properties of crude shipments can cause failure mechanisms** such as corrosion or cracking, or to contribute to them via operational problems, e.g., overpressurization, interference with corrosion mitigation measures.
3. **Compare the failure-relevant properties of diluted bitumen shipments with those of other crudes shipped** through U.S. pipelines.
4. **Determine whether the relevant properties of diluted bitumen shipments are outside or at the extreme end of the range of properties found in other crude shipments** so as to suggest a higher potential to cause releases.

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"Historical record" of incidents not very useful (doesn't provide a baseline)

- Dilbit transported in same pipeline network as other crudes
- Not possible to ID parts of network that have seen different amounts of Dilbit
- Pipeline network is heterogeneous with respect to age, materials, construction, corrosion mitigation, etc.
- Incident reports of failure modes not very detailed or useful; don't specify material released or history of past shipments

We decided to take the pipeline system "as is", ask if there are differences between Dilbit and other (heavy) crudes that would exacerbate failure mechanisms

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CONTRAST BETWEEN RELEASE "CONSEQUENCES" vs. "LIKELIHOOD" STUDY:

- Information is available about major Dilbit releases (Marshall, MI; Mayflower AR) and subsequent environmental experience

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Summary of Failure Mechanisms with Potential Connections to Crude Oil Properties

Three broad categories of failure causes:

1. **Internal degradation**
   - **--internal corrosion**
   - **--internal erosion**

2. **External degradation**
   - **--external corrosion**
   - **--cracking**

3. **Mechanical force damage**
   - **--Pressure surges**

Internal Corrosion

- **Water must be present in crude stream and in contact with pipe bottom—oil by itself is not corrosive to pipe steel.**
- **Sediment in crude shipments that deposits to the pipe bottom can exacerbate corrosion by forming sludge with water.**
- **CO_2, H_2S, and Oxygen in crude stream can exacerbate corrosion if dissolved in water contacting the pipe bottom.**
- **Acids in crude can exacerbate corrosion if dissolved in water.**
- **Microorganisms in water-laden sludge can cause corrosion.**
- **Maintaining turbulent flow in pipelines is important to keep water and sediment suspended.**

Internal Corrosion

Desired Information

- **Water**
- **Sediment**

} Basic sediment and water (BS&W), fraction of each

- **CO_2, H_2S, and Oxygen** + sulfur content and type
- **Acids:** amount (TAN) and type
- **Microorganisms:** potential nutrients (carbon form, nitrogen content and form)
- **Maintaining turbulent flow:** viscosity, operating characteristics

Representative Sources of Information

- **Pipeline "tariffs" – Canada and US** – specify acceptable ranges for
  - Density (API gravity)
  - Viscosity
  - BS&W
- **CrudeMonitor.com (Crude Quality Inc.)** – analysis of
  - Density
  - Viscosity
  - Sediment content
  - Hydrocarbon composition
  - Distillation temperatures
  - Sulfur content
  - TAN number
- **Presentations to the committee** from
  - CANMET
  - Canadian Crude Quality Technical Association
  - Alberta Innovates
  - Suncor Energy
- **Pipeline Operators survey responses** – ranges of above properties plus
  - Operating temperature
  - Flow rate
  - Pressure

How does diluted bitumen compare?

- **Water and sediment—pipelines in Canada have stricter standards than U.S. for shipment water and sediment levels. Levels in diluted bitumen shipments are not higher than in other crude oil shipments.**
- **Dissolved gases— H_2S content lower than in other crudes. No reason to believe CO_2 or oxygen levels are higher for shipments stored that same way and transported in the same pipeline systems.**
- **Acids—Diluted bitumen has high total acid, but the acid is not soluble in water and not reactive at pipeline temperatures.**
- **Microorganisms—not higher, diluted bitumen lacks essential resources for growth. Sulfur is bound in HCs.**
- **Turbulent flow—diluted bitumen is transported under conditions of turbulent flow and higher density helps suspend water and sediment.**

Comments about Information Sources

- **We were criticized for not doing our own analyses, relying on "industry" data**
  - NRC committees have no capability for doing such analyses
  - Would not be able to analyze a statistically relevant number of samples even if they did
- **You can expect the same criticism!**
- **The Industry is not monolithic**
  - Producers
  - Pipeline Operators
  - Refiners
- **Each group along the supply chain needs reliable information from the ones upstream**

Internal Erosion

- **Not a major concern in crude transmission pipelines.**
- **Solid particles in sediment can be abrasive if transported at high flow velocity.**
- **No information on abrasiveness of solid particles in diluted bitumen vis-à-vis other crudes.**
- **Diluted bitumen shipments are not transported at higher flow velocity than other crude shipments.**
- **The diluted bitumen piped to U.S. is not mined bitumen, but extracted in situ. In situ bitumen has lower solid content than mined bitumen.**

External Corrosion and Cracking

- **Shipments do not contact the outside of the pipe.**
- **High and fluctuating operating pressure can create stresses that cause or exacerbate cracking.**
- **Elevated operating temperature can cause disbonding of exterior coating (which protects against external corrosion).**
- **Viscous crudes require higher pressure to maintain same flow velocity.**
- **Viscous crudes require more pumping energy to maintain flow velocity—translates to higher operating temperatures.**

How does diluted bitumen compare?

- **Shipments of diluted bitumen are viscous, but purposely diluted to viscosity levels comparable to other heavy crude oil shipments.**
- **Diluted bitumen shipments will not require more pumping energy than other heavy crude oil shipments—thus operating pressure and temperature will be the same.**
- **When setting pressure, pipeline operators must not exceed stress level ratings for their pipelines.**
- **Operators reduce flow rates (while still maintaining turbulent flow) rather than increase operating pressure when transporting viscous shipments.**

Mechanical Force Damage

- **Pressure surge events are main concern.**
- **It has been claimed that the diluent in diluted bitumen separates into gas phase in pipeline, causing a vapor void that will collapse to cause a damaging pressure surge (analogous to water hammer).**
- **Diluted bitumen is mixed to be fully miscible, or uniform in all proportions—no evidence that it is unstable in pipelines.**
- **Light-end, high vapor pressure component (C_4- C_{10}) of diluted bitumen is smaller than medium and light crudes.**

O&M Procedures

- **Pipelines move multiple grades of crude oils in shipment batches (~100,000 barrels).**
- **O&M procedures must be robust to accommodate range of crude shipments in transport.**
- **No evidence that operators change their O&M procedures when shipping diluted bitumen compared with other heavy crudes or that O&M changes are necessary.**

Summary of Study Results

- **The committee did not find any causes of pipeline failure unique to the transportation of diluted bitumen.**
- **The committee did not find evidence of physical or chemical properties of diluted bitumen shipments that are outside the range of other crude oil shipments or any other aspect of its transportation by pipeline that would make diluted bitumen more likely than other crude oils to cause releases.**
  - **Diluted bitumen shipments do not have unique or extreme properties that make them more likely than other crude oil shipments to cause internal damage to transmission pipelines from corrosion or erosion.**
  - **Diluted bitumen shipments do not have properties that make them more likely than other crude oil shipments to cause damage to transmission pipelines from external corrosion and cracking or from mechanical forces.**
  - **Pipeline operating and maintenance practices are the same for shipments of diluted bitumen as for shipments of other crude oils.**

Differences in information needs/relevance when considering Dilbit outside vs. inside the pipe

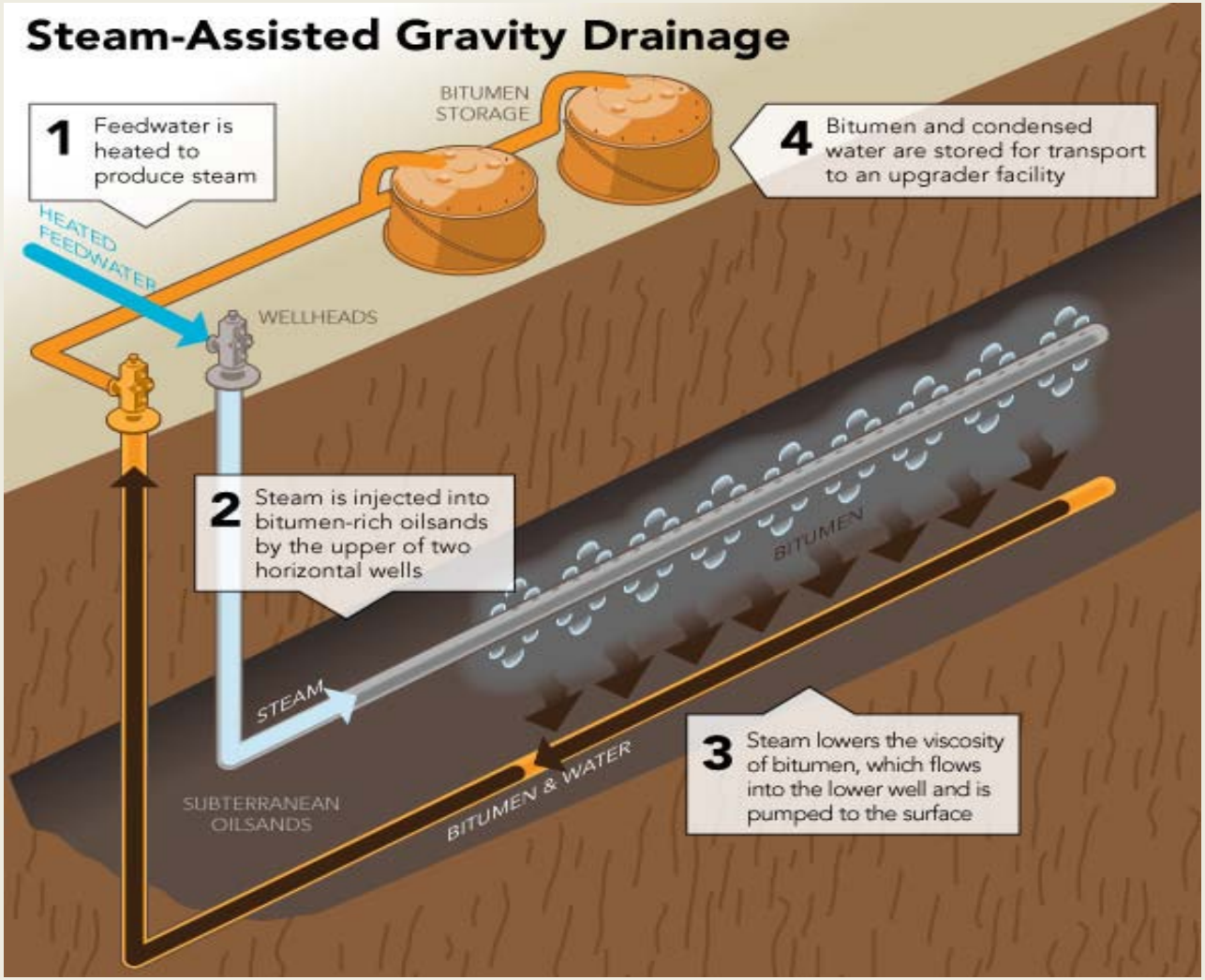
- **Empirical evidence regarding consequences of release/fate in the environment**
  - Pipeline releases
  - Crude characteristics that have been consequential in other spills
- **Some of the relevant chemical and physical properties needed to compare Dilbit with other crudes will be different from those in our "likelihood of release" study**
  - Volatility or solubility of components that may lead to phase separation of released material (or its reaction products)
  - Partitioning and transport of crude components in soil, water and air
  - Chemical and photochemical reactivity of crude components
  - Biological uptake of crude components (and reaction products)
  - Clean-up and remediation techniques

Backup Slides

Oil sands mixture of clay, sand, and bitumen

Extracted bitumen (undiluted, heated)

Diluted bitumen



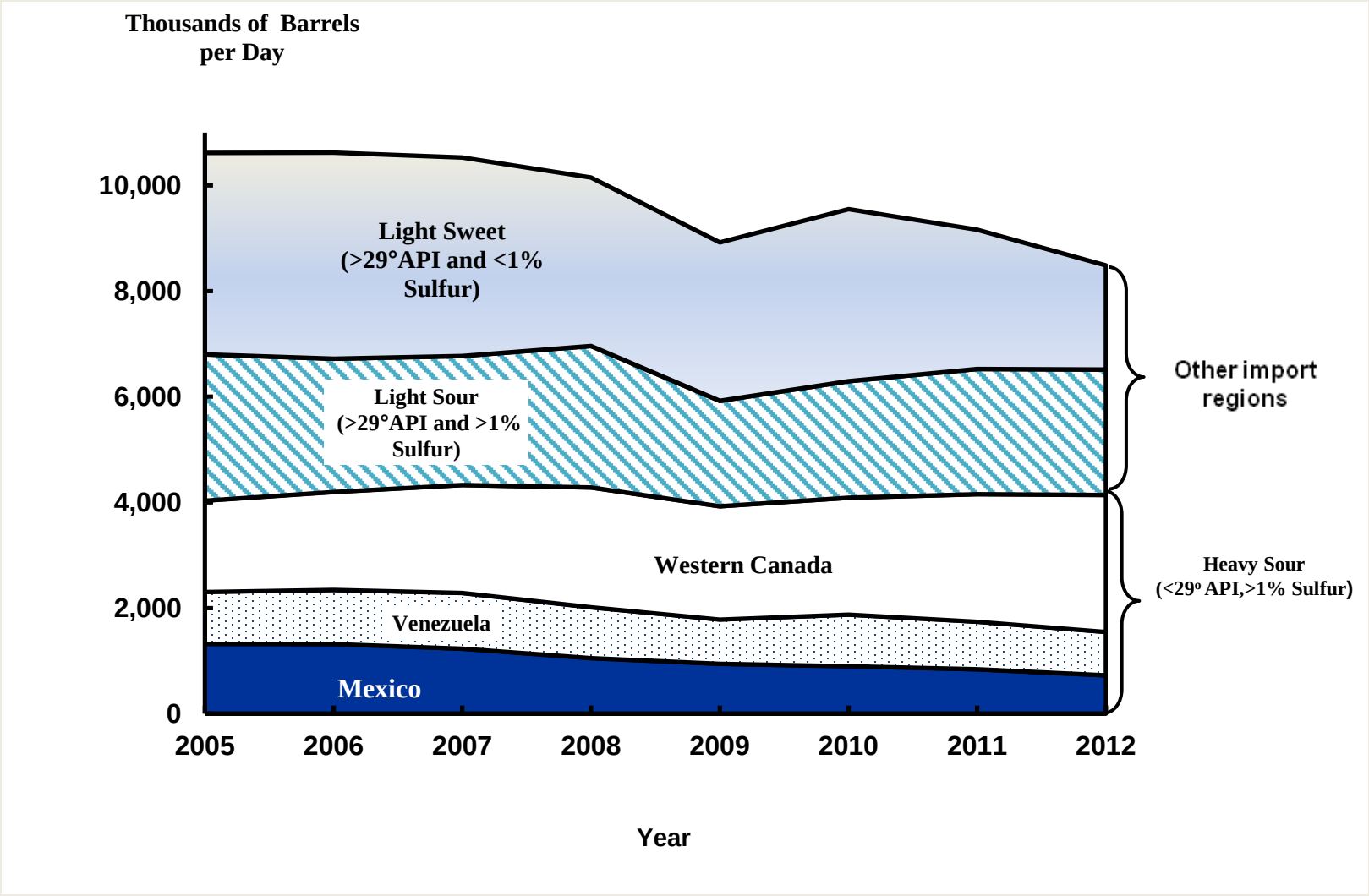
Bitumen extraction using SAGD

Example Blending Ratios and Density and Viscosity Levels for Synbit and Dilbit

Blend Component	Volume Percent	Density (kg/m^3)	Viscosity [cSt at 15^oC (59^oF)]
Synbit			
Bitumen	51.7	1,010	760,000
Synthetic crude oil	48.3	865	5.9
Total	100	940	128
Dilbit			
Bitumen	74.6	1,010	760,000
Condensate	25.4	720	0.6
Total	100	936	350

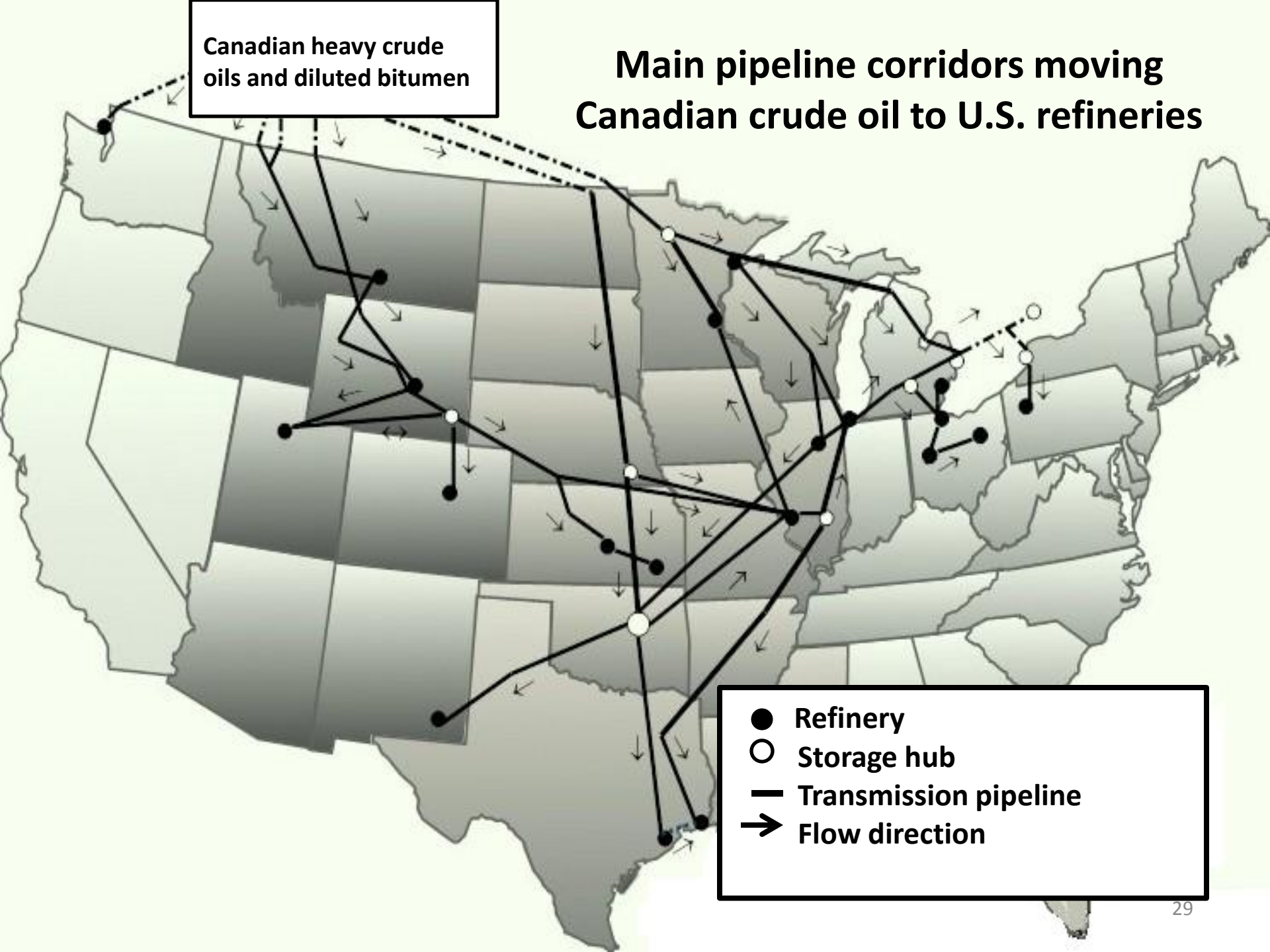
Selected Properties of Two Common Diluents Blended with Canadian Bitumen

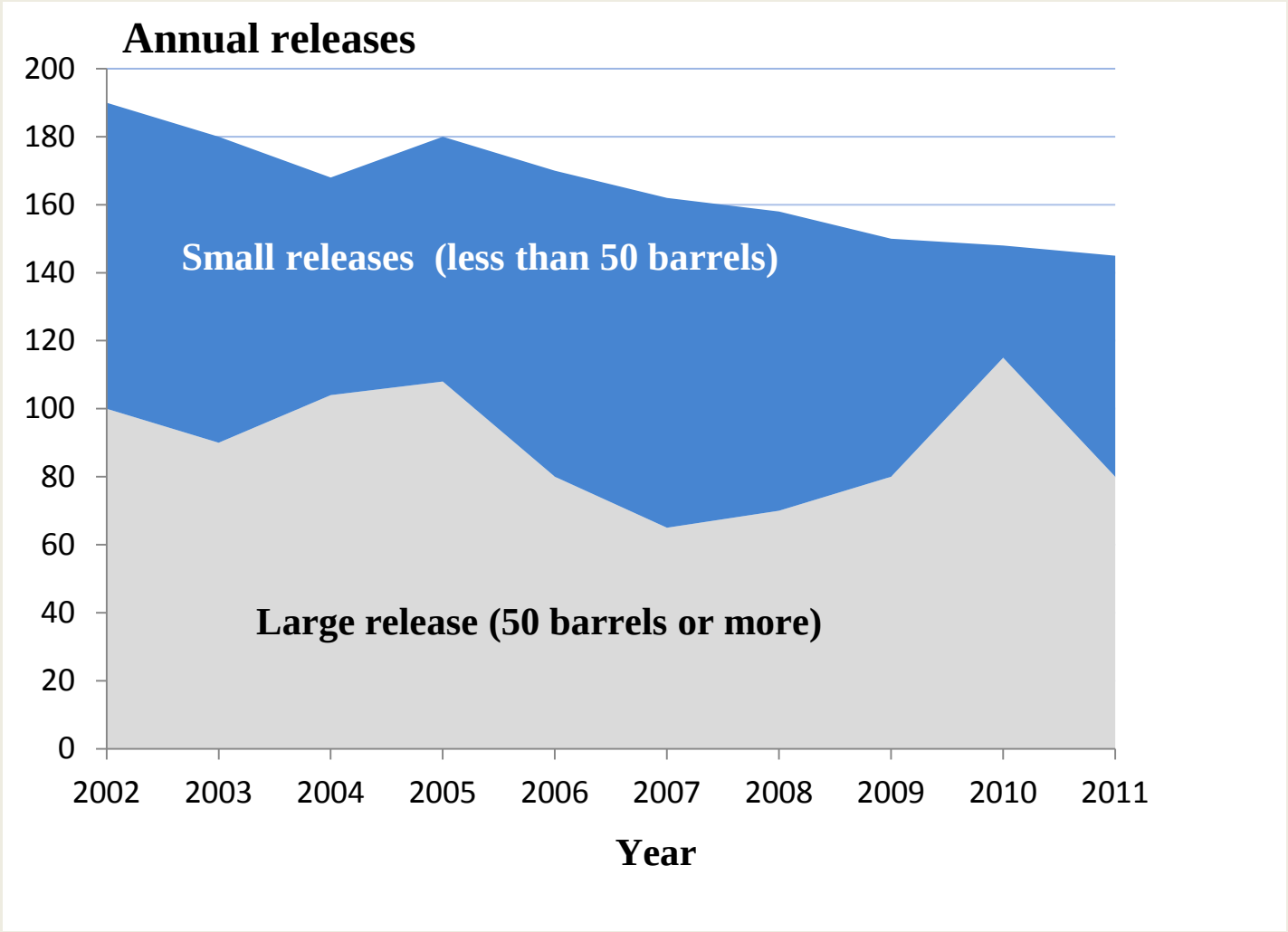
Property	Southern Lights Condensate Diluent	Suncor Synthetic Crude Oil Diluent
Density (kg/m^3)	675	861
API gravity (^{o})	78	33
Sulfur (weight percent)	0.03	0.17
Viscosity at 20^{o}C (68^{o}F) (cSt)	<0.5	6.3
Sediment (parts per million by weight)	16	0



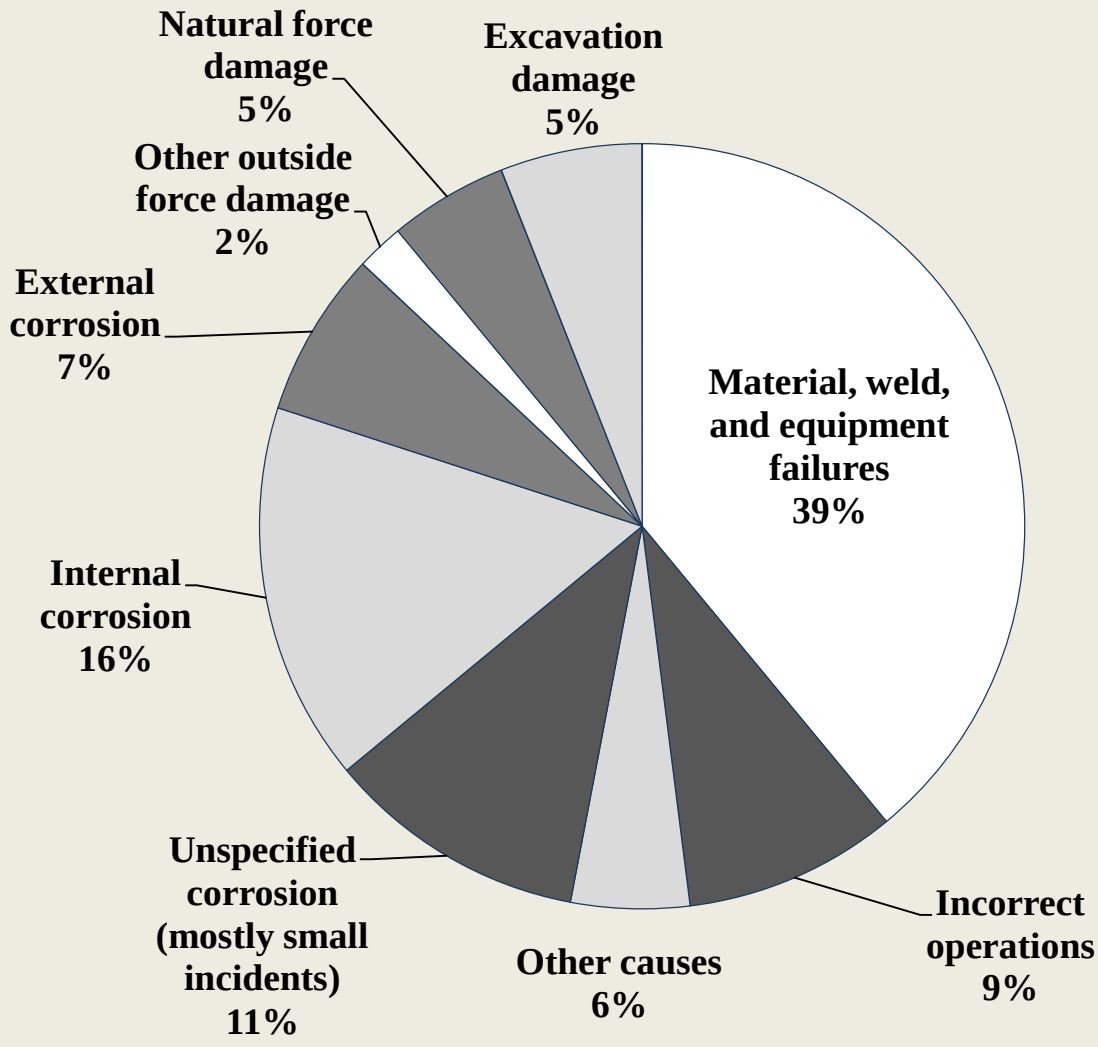
Annual U.S. crude oil imports by grade and origin

Main pipeline corridors moving Canadian crude oil to U.S. refineries

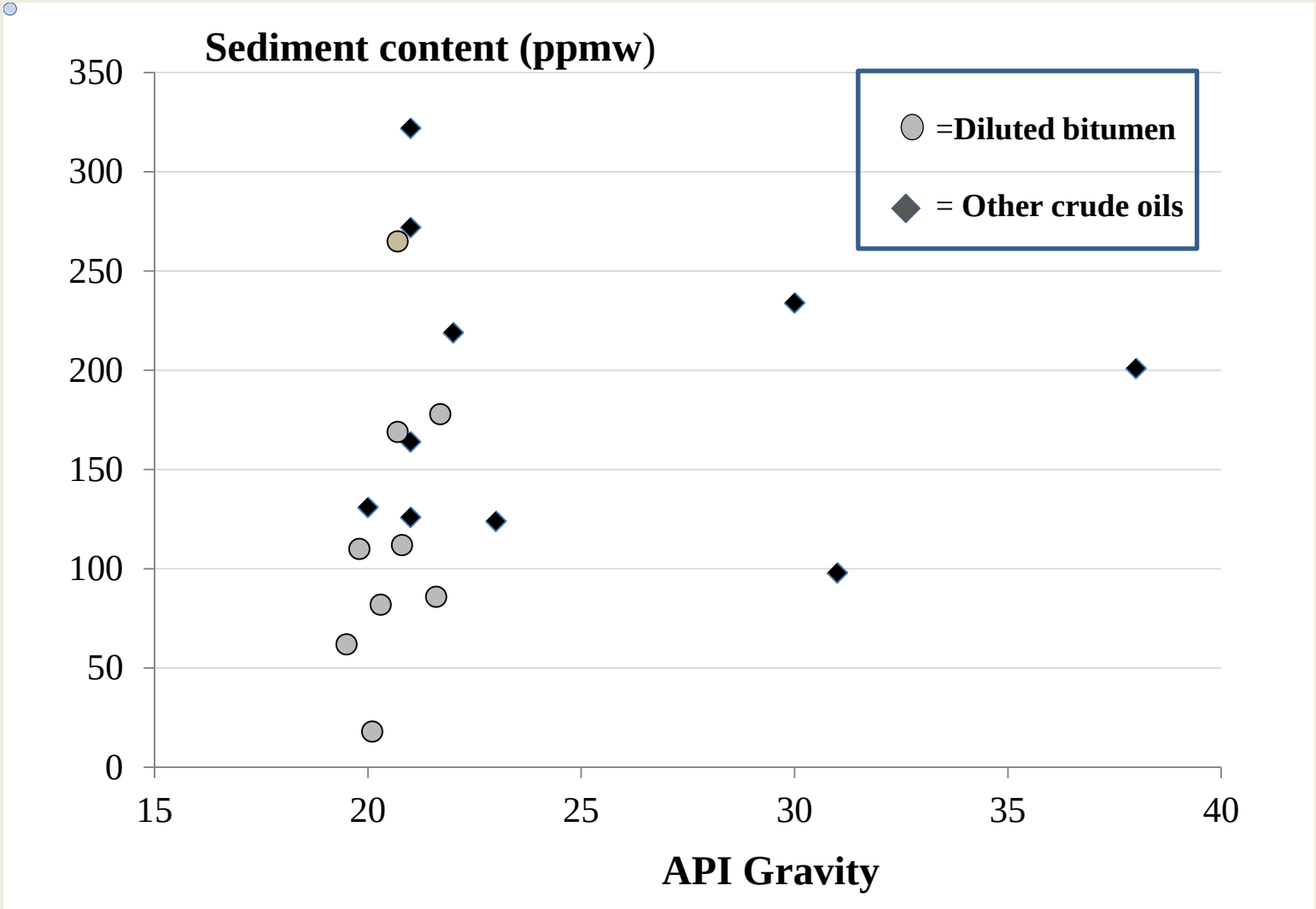




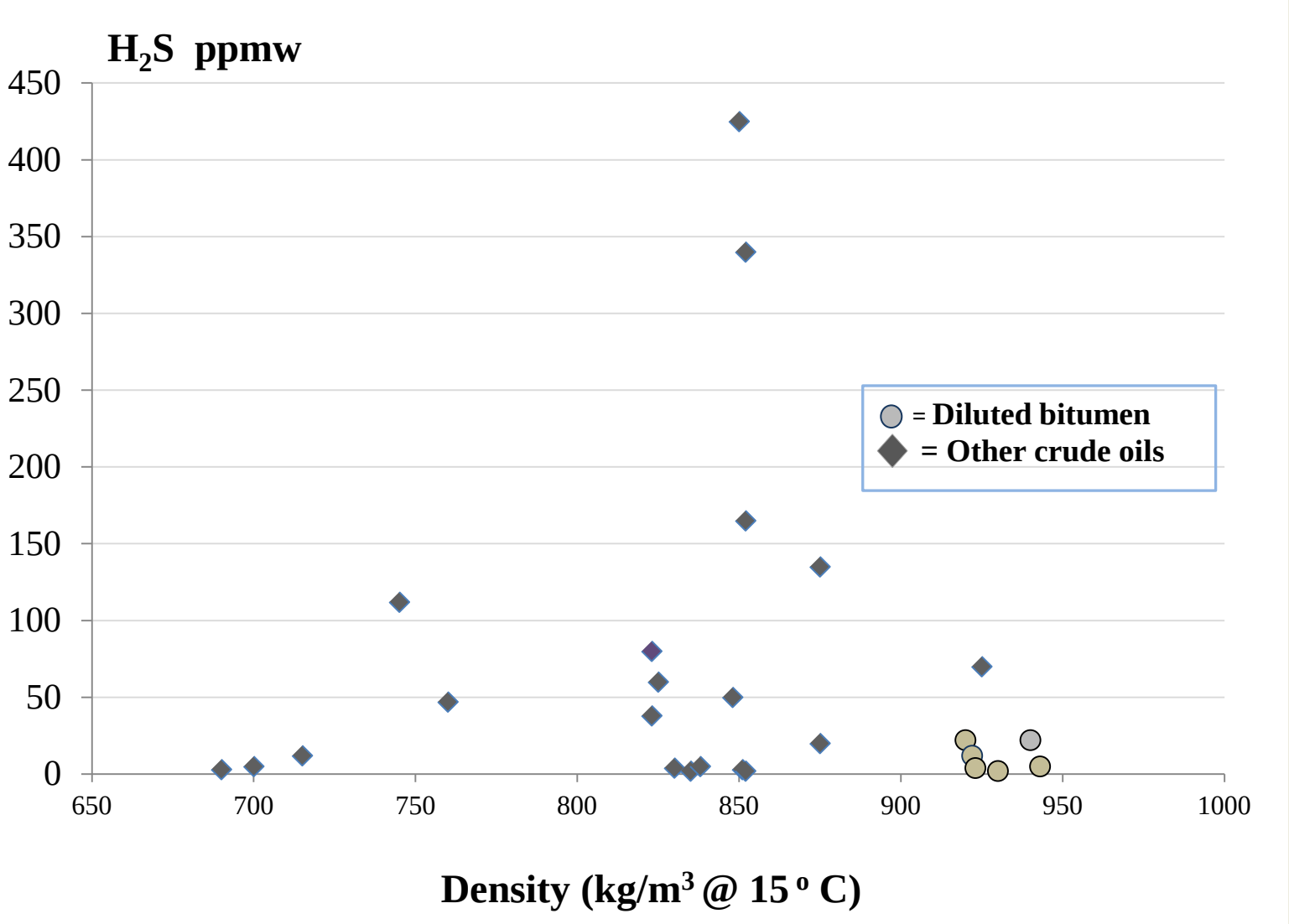
Crude oil pipeline incidents reported to PHMSA, 2002 to 2011.



Causes of crude oil pipeline releases reported to PHMSA, 2002 to 2011



Average sediment content for nine diluted bitumen blends and 10 light, medium, and heavy Canadian crude oils.



Measured H_2S content of diluted bitumen and other crude oils.

Sulfur and Total Acid Content in Sampled Canadian Heavy Crude Oils and Diluted Bitumen Blends

	Total Sulfur (percentage by weight)	TAN (mg KOH/g oil)
Canadian Heavy Crude Oils		
Fosterton	3.26	0.2
Lloydminster Blend	3.56	0.82
Lloydminster Kerrobert	3.12	0.92
Western Canadian Select	3.51	0.94
Diluted Bitumen Blends		
Albian Heavy Synthetic	2.5	0.57
Access Western Blend	3.93	1.72
Black Rock Seal Heavy	4.32	1.72
Cold Lake	3.75	0.99
Christina Lake	3.79	1.53
Peace River Heavy	5.02	2.5
Smiley–Coleville Heavy	2.97	0.98
Statoil Cheecham Blend	3.69	1.77
Surmount Heavy Blend Synbit	3.02	1.38
Western Canadian Blend	3.1	0.82

Comparison of Density, API Gravity, and Viscosity of Diluted Bitumen and Other Canadian Crude Oils Canadian Heavy Crude Oils

Canadian Heavy Crude Oils

	Bow River	Fosterton	Lloydminster Blend	Lloydminster Kerrobert	Smiley–Coleville	Western Canadian Blend
Density (kg/m^3)	914	927	927	930	932	929
API gravity (^{o})	23	21	21	20	20	21
Viscosity at 20 ^{o}C (68^{o}F) (cSt)	100	96	145	146	144	145
Viscosity at 40 ^{o}C (104^{o}F) (cSt)	37	36	52	52	51	52

Diluted Bitumen

	Access Western	Cold Lake	Peace River Heavy	Christina Lake	Wabasca Heavy	Surmount Heavy (Synbit)
Density (kg/m^3)	926	928	931	923	935	936
API gravity (^{o})	21	21	20	22	20	19
Viscosity at 20^{0}C (68^{o}F) (cSt)	150	153	113	178	134	131
Viscosity at 40^{0}C (104^{o}F) (cSt)	53	54	44	62	49	47

Summary of Properties and Operating Parameters of Diluted Bitumen Shipments Reported by Pipeline Operators

Property or Parameter	Unit	Range of Reported Averages	Lowest and Highest Values in Reported Normal Ranges	Highest Reported Extremes
BS&W	Volume percent	0.18 to 0.35	0.05 to 0.40	0.50
H_2S	ppmw	<0.50 to 6.77	<0.50 to 11.0	11.0
Sulfur	Weight percent	3.10 to 4.00	2.45 to 4.97	5.20
Density	API gravity	19.8 to 22.1	19.0 to 23.3	23.3
TAN	mg KOH/g	1.00 to 1.30	0.85 to 2.49	3.75
Operating Temperature	^oC (^oF)	10 to 27 (50 to 81)	4 to 43 (39 to 109)	50 (122)
Flow rate	feet/second	2.5 to 6.7	0.5 to 8.2	8.2
Pressure	psi	430 to 930	43.5 to 1,440	1,440